Guide to Defense & Aerospace Expert Systems

by Alton K. Marsh

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Alton K. Marsh

Managing Editor for

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PREFACE

Expert systems developments are proceeding at a rapid pace, fueled by astronomical increases in processing speed and memory capacity. The defense and aerospace industries, backed by research dollars from the federal government and immediate application needs by the military's "smart weapons" programs, is leading the way in areas like natural language, fuzzy logic, simulation, machine vision, voice recognition, and real-time processing.

The "Guide to Defense & Aerospace Expert Systems" is an overview of recent successes, failures and advances in the field of Artificial and Machine Intelligence. Taken from in-depth feature coverage in the pages of ADVANCED MILITARY COMPUTING, it is your source for the programs, participants and opportunities that exist in this burgeoning field. Edited by Alton K. Marsh, author of the comprehensive industry report "Guide to the Advanced Military Computing Market," you will find "Defense & Aerospace Expert Systems" to be a valuable asset to your research tools.

The "Guide to Defense & Aerospace Expert Systems" is published by Pasha Publications, publisher of ADVANCED MILITARY COMPUTING, C3I REPORT, MILITARY SPACE, SPACE BUSINESS NEWS and SDI MONITOR. Covering important trends, developments and opportunities in commercial and military space programs and advanced computing technologies, these industry newsletters provide readers with bottom-line news and analysis. For more details about Pasha newsletters and other information products, call Cliff Gibbs toll-free at 800-424-2908 (703-528-1244 in the Washington, D.C. area); or write Pasha Publications, 1401 Wilson Blvd., #910 Arlington, Va. 22209.

Table of Contents

Chapter One

Does Artificial Intelligence Have a Military Future?

1.1 A Lot of Concerns

Artificial intelligence, currently a reincarnated computer revolution, is headed for another stumble but will survive, instructors at a military artificial intelligence conference in Los Angeles said recently.

Their concerns about another stumble, caused by too much hype and too little performance, were heard a few days later at a similar conference in Washington, D.C.

"There are a lot of new artificial intelligence (AI) companies out there, and half of them are no good. Their only connection to the field is their ability to spell AI and they are going to damage funding for the rest of us," an official of Advanced Decisions Systems worried recently after a speech in Washington.

His concern was borne out in a series of speeches presented in Los Angeles by instructors at a course on "Artificial Intelligence and National Defense: Applications to Command and Control and Beyond." The course was

presented by the Armed Forces Communications and Electronics Association (AFCEA).

Increasingly, opinions of responsible officials in the artificial intelligence expert systems industry show concern that hype is winning over substance. Instructors at the AFCEA class, taught at the Navy and Marine Corps Reserve Center near Dodger Stadium, noted that although there may be another chill in AI interest coming, the technology will prevail.

The next reincarnation -- a more durable one -- will occur in applications of the technology with less emphasis on research, the AFCEA class was told. Most of today's artificial intelligence expert systems exist only in prototype, forcing military leaders to note, as an Army Material Command general did late in 1985 in Austin, Tex., "It hasn't done anything for us yet."

Artificial intelligence as it is known today will evolve (it is an evolution, not a revolution) into a set of methods for intelligent information processing, AFCEA instructors said. The 56 attendees at the AFCEA course were assured that government research support will continue through the Defense Advanced Research Projects Agency Strategic Computing Program and the Strategic Defense Initiative. However, the current infusion of industry money will taper off and be redirected according to Defense Dept. investment trends and low-risk, high-payoff opportunities.

AI has proven an expensive research area for industry. New AI researchers with doctorate degrees are commanding salaries of $75,000 to

$85,000. The tools used such as the Symbolics AI computer can cost $20,000 to $30,000 per year just for support, AFCEA course participants were told.

Major corporate players in AI technology as identified in the AFCEA course are: Bolt Beranek Newman, Digital Equipment Corp., Fairchild, General Motors, Hewlett Packard, Hughes, Machine Intelligence Corp., Schlumberger, Texas Instruments, Teknowledge, TRW, and Xerox/Parc. Identified as "minor" players in a textbook accompanying the AFCEA course were: Advanced Decision Systems, Computer Thought Corp., Cognitive Systems, Information Systems, Perceptronics, Smart Systems Technology, and "Too many others to name," course literature stated.

Programs that will need AI include the Strategic Defense Initiative, Ballistic Missile Defense, C3I Data Fusion, and the Aquila remotely piloted vehicle program.

Businesses considering an investment in AI were advised to do so only if their commitment and business projections are solid. If the backlog is small and internal commitment is questionable than AI needs should be obtained through subcontracts and consultants.

It is interesting to note that concerns over artificial intelligence hype are coming from the supporters, not detractors. Such concern appeared in "Sigart," the newsletter of a Dayton, Ohio special interest group on artificial intelligence made up of 500 aerospace personnel.

"The primary shortcoming of present knowledge-based systems is that they are inflexible," Mike McCown of Rome Air Development Center wrote in the newsletter. "If new information is input to the system which is not explicitly represented in the knowledge base, similar though it may be to previous inputs or existing representations, the system cannot deal with it unless explicitly told how. This lack of generalization and analogy capability causes a great bottleneck in the maintenance of the system, requiring experts and knowledge engineers to continuously update the knowledge base to reflect the current possibilities of input. In the rapidly changing real world this is unacceptable."

McCown went on to note that his concerns are not new.

"What I would like to add to the discussion is my belief that the current methods of knowledge representation are fundamentally incapable of solving the learning problem due to their discreteness. While discrete, cleanly delineated representations are (relatively) easy to work with, program well, and are easy to implement using the discrete representations that binary, von Neumann machines offer, these representations, due to this very discreteness, do not and can not represent reality in any generic and flexible way. Solutions along the lines (or at least in the spirit of) coarse coding, distributed representation, etc., seem to be a possible solution to some of these problems," he said.

McCown said the representations are not useless. They can still be used as programming techniques for some types of analysis problems.

1.2 Intelligence Community a Strong Market

Having warned about going overboard with artificial intelligence expectations, it should also be noted that there are successes with expert systems in the intelligence community.

The Central Intelligence Agency has established a computerized intelligence analysis room with 12 Xerox Golden Tiger intelligence analyst work stations to research the potential for use of artificial intelligence.

The work stations are linked to an IBM mainframe computer.

Use of the work stations was described for the Naval Research Advisory Committee panel on artificial intelligence which met at Woods Hole, Mass. in 1985.

The National Security Agency has developed an intelligence analysis system using artificial intelligence for its R5 section. The system has been completed under contracts to universities and is being distributed within NSA.

Briefings given to the Naval Research Advisory Committee in 1985 show that some of the strongest markets for AI applications are in surveillance, image understanding and intelligence analysis. All the intelligence

applications of AI require supercomputers that are faster than those available commercially.

Additionally, Air Force intelligence officers have asked the Rome Air Development Center for a special instructional course on potential applications of artificial intelligence.

1.3 Air Force Space Command is Among the Cautious

The chief scientist of the Air Force Space Command in Colorado Springs says the command will be "very cautious" in introducing artificial intelligence into such critical command activities as missile early warning and attack assessment.

In an interview John Darrah said he is particularly interested in hardware and software improvements for tactical warning, attack assessment processing and display in the Space Command/NORAD command post inside Cheyenne Mountain, which is located outside Colorado Springs.

"We're an information command that uses not only its own sensors but third-party sources -- intelligence, CINCLANT, etc.," he said.

"I track closely what's going on in AI and expert systems," Darrah said. "Most command activities, such as those in tactical warning and attack assessment, are now done by pattern recognition. That's now done

best by the human brain, which is good at parallel processing. We want to be slow in leaping to mechanize, since we don't want to underestimate what the mind can do in such activity."

Asked about the difficulties of certifying AI techniques for NORAD operations, Darrah said new techniques would be needed to formulate general problems and devise specific machines that could take user software and rewrite it in specific ways.

"How do you trade off a LISP machine and a number cruncher?", he asked. "How do you devise natural-language inquiries?" He added that Space Command/NORAD uses between 20 and 30 million lines of code, much of which could be incorporated into any future SDI system.

1.4 Is AI Ready for Land or Space Battle?

Expert systems do not come close to solving battlefield or space-based defense problems, two researchers have concluded in a scientific paper.

Michael S. Crone of Harris Corp., Melbourne, Fla., and David L. Hall of HRB-Singer, State College, Pa., told an expert systems symposium in McLean, Va. expert systems cannot direct "real-time" battlefield problems.

"This does not mean it cannot happen, but it does mean that some very definite advances in AI [artificial intelligence] must still occur before it becomes a reality," the men concluded.

Changes are needed in the government procurement system to close gaps between customer (government) expectations and the final product, Crone and Hall said.

Government requests for proposals for expert systems should be divided into a request to model the requirements and a second request to model the solution, they said. The first phase would aim towards proof-of-concept. If unsuccessful, procurement would not proceed. If the concept is proven, the expert system would be built in the second phase, they said. The second phase would proceed deliberately, with development occurring in successive demonstration models.

The customer and contractor should meet monthly in a relaxed atmosphere free of the usual "dog-and-pony-show" technical presentations, they said.

1.5 Something the AI Salesmen Won't Tell You

Few companies considering purchase of an expert system building tool such as ART or KEE realize they still need programmers to build expert systems, Robert C. McArthur of Arthur D. Little, Cambridge, Mass. has told an expert systems seminar.

McArthur addressed the "Expert Systems: Executive Training Program," sponsored by Larus Inc., Jamestown, R.I. at the Cambridge Hyatt.

"That's not to say shells [software programs used to create expert systems] aren't useful," McArthur said in an interview after his speech. "They provide quite a lot, but not enough. You have to add procedural portions to the expert system. Anything having to do with input/output and problem-solving strategy is procedural.

"There is a misconception that an expert system building tool is all that is needed. There will always need to be programmers," he said.

"Out of the dozen or more expert systems we have worked on, no expert system building tool by itself was enough to create an expert system that is anywhere near useful. They are simply not enough," McArthur said.

"They represent facts and rules, but not procedural knowledge," he said.

Arthur D. Little is working on a weather forecasting expert system for Kennedy Space Center, and is doing other systems for the Environmental Portection Agency and Litton. They range across a spectrum of applications, from planning and design, trouble shooting, diagnostics, and configuration to process control for industry. The firm has used KEE, by IntelliCorp, which McArthur said has paid for itself many times over. He added that ART, by Inference, is coming into use at Arthur D. Little. The firm has also

used the artificial intelligence language PROLOG, and has used expert system building shells developed in-house.

Firms following McArthur's advice should be aware that while an expert system building tool is very useful, they will still need people on the staff proficient in the language being used, whether it is LISP, PROLOG or some other language. Companies selling such tools often fail to mention that, McArthur said.

"A lot of the value of the programming tools is they allow you to make mistakes and recover quickly," he told the audience of 33 industry and government managers.

McArthur is concerned about another aspect of expert systems as well: once they are in use, workers will feel the system frees them from exercising judgement. "There is a potential possibility that people will think these systems are going to think for them, thereby causing human operators to lose expertise," McArthur said during a question and answer session following his speech.

Arthur D. Little software engineers have written a memo to Inference, suggesting changes in ART. The memo, while not released by the firm, has suggestions similar to those in an evaluation by the National Aeronautics and Space Administration. NASA's Johnson Space Center has used ART, KEE and OPS5 for expert system building, and has made suggestions for changes in all of them.

As a general rule, McArthur warned that his firm has discovered that "real-time" expert systems are "real hard" to develop.

Chapter 2

Military Expert Systems

2.1 Advanced Decision Systems

AI System Analyzes Soviet Radars

A prototype of an artificial intelligence expert system to analyze Soviet radar signals for evidence of technological breakthroughs has been delivered to the U.S. intelligence community by Advanced Decision Systems (ADS), Mountain View, Calif.

ADS official Andrew S. Cromarty would not identify the customer, but described the system during a two-day seminar sponsored by the Defense Electronics Association presented in Atlantic City, Boston and Washington. The seminar was titled: "Military Decision Support Systems."

The customer is involved in intelligence work either as a government agency or as a government contractor.

The software program is called the Science and Technology Analyst's Assistant, an expert system to analyze radar signal reports. It provides a state-of-the-art user interface to make it easy to use, a single-user workstation computer console, and a multiple-process, functionally partitioned message passing architecture.

The system brings some of the problem-solving approaches of an expert to the junior radar analyst, but is useful to the advanced analyst as well. With it the junior analyst can determine whether the signal was produced by a known radar system and if not, how it differs from known signals.

ADS officials found analysts are more effective with a keyboard than with a mouse pointer or touch screen, and decided to operate the system totally from the keyboard. It uses the MRS inference engine developed at Stanford, and can run on a DEC VAX, Symbolics or Sun computer using FranzLisp or ZetaLisp.

Cromarty also made these observations on the future of computerized military decision support:

---Parallel computing which offers a speed advantage is finally here, but it will be three to 10 years before we really know how to program them;

---Distributed processing for artificial intelligence systems is still at the research stage. There is no general agreement on the right way to distribute knowledge and processing across multiple processors;

---Full automation of decision making will be necessary for the more difficult problems where human expertise does not exist, in hostile environments were there are unreliable communications paths to humans, and in cases where there is too much information to sort through. People will still prefer to make critical strategic decisions themselves. Social politics will not permit automation of some functions. Progress towards machine decision making will be slow enough that public policy can adjust to the idea;

---Ada, the computer language developed and trademark-protected by the Pentagon, is "...clearly designed by a committee that had some wrong ideas about designing a language. There was no real cost to the committee to add features to the language, so they did. A large language [which resulted] costs a great deal to maintain;"

---Voice and natural language are lagging well behind visual information transmission. Producing language is easier than making a machine that understands it;

---The weak link in most expert systems is the narrowness of the knowledge and the way it is represented. Knowledge engineers must be skilled interviewers to extract the expert's knowledge, and they will have to learn something about it themselves.

2.2 Advanced Decision Systems

Airborne EW Expert System Built

Advanced Decision Systems, Mountain View, Calif., has built an expert system prototype to relieve fighter pilot workload by integrating and coordinating the many systems that make up an electronic warfare suite.

The system employs two distinct object-oriented programming languages to model the conceptual processing nodes and capabilities of an automated electronic warfare system. They are: Zetalisp Flavors, and Systems Oriented Language developed by Advanced Decision Systems.

An electronic warfare suite detects, recognizes and responds to threats by gathering data from a number of sensors, allocating the sensors based on the threat and providing countermeasures. Those tasks are normally managed by an electronic warfare officer, but an expert system is needed to manage those same tasks on a single-seat fighter, said James F. Cunningham, one of the scientists on the project.

The expert system prototype performs the electronics warfare task in a simulated environment at present. Threat models are defined using Flavors, while the expert system itself uses Systems Oriented Language.

The system is knowledge based, and uses knowledge gathered from pilots and electronics warfare specialists. The simulator, used as a development tool, allows a user to generate scenarios and monitor processing through an interactive, icon-oriented user interface.

"What is really new," Cunningham and other scientists wrote in an Advanced Decision Systems paper on the system, "is the planned combination of sensor, jammer and expendable stores [chaff, flares] into integrated systems. Historically, radar warning receivers, countermeasures sets, infrared expendables, chaff and electronic decoys were procured separately and controlled on board by an electronic warfare officer as essentially standalone black boxes.

2.3 Air Force

Air Force Places Seven Expert System Decision Aids in Advanced Development

Rome Air Development Center, Griffiss AFB, N.Y. has selected seven expert system decision aids for advanced development. In Fiscal Year 1987 the Air Force sought $8.6 million for the advanced development work and will seek $12 million in 1988.

The seven expert system projects are:

---A Dynamic Order of Battle Aggregation expert system aid (DAGR) that aids analysts in updating enemy aircraft capabilities:

---Identification of the enemy's command and control nodes through an expert system, similar to DAGR, is the goal of the Doplex Army Radio/Radar Targeting aid (DART). It will process and analyze data collected on enemy command and control ground positions for air defense purposes, select

targeting sites and lay out scenarios that cover the configuration of the enemy system;

---A C3CM Planning Analyzer (CPA) will assist in identifying opportunities and interactions from collected data and form an action plan. The data concerns enemy deployments and countermeasures initiated by the enemy.

---The Target Planning Aid (TPA) assists in deployment of force against a target through prioritization. The work is being performed by Knowledge Systems Concepts, Perceptronics, PAR Technologies, Betac and DataDesign Inc.

---Iterative Planning Optimization (IPO) is a real-time aid that would coordinate between different levels of action planned against an enemy to produce a workable mix. The work is being done by Advanced Decision Systems and Betac.

---A Command Management Aid, an outgrowth of the senior battle staff management aid development project, provides decision capability for the commander and staff.

---A Coordinating Expert Systems Aid (COPES) integrates all the above expert systems into a cooperative approach at the command level. This work is being done by Calspan.

2.4 Air Force

AI to Analyze Space Threats

Warning of strategic satellite threats from space will be provided by an artificial intelligence expert system to be developed after 1987 under a technology plan established by the Rome Air Development Center, Griffiss AFB, N.Y.

The indications and warning expert system would be applied to selected launch scenarios to distinguish normal satellites from those which vary slightly from established launch patterns, or have never been seen before (such as launching to new orbits not normally used).

The expert system will be used on a Symbolics 3600 Lisp machine using the Metalevel Representation System to codify and store the knowledge of a human expert in the software.

The completed system will have these capabilities: identification and interpretation of selected satellite launches, use of deductive and inductive analysis techniques, tracking and processing multiple missions, production of sensor tasking, and hypothesis of current and future activities.

Igor G. Plonisch, a computer scientist with Rome Air Development Center, said in an article in "Signal," that the work will build on current work in progress to upgrade resources and capabilities used by space

intelligence analysts. The current project began in 1984 and ends in 1987. Space intelligence software is being rebuilt into a cohesive operational system with improved analytical capabilities. It uses the IBM 3083EX mainframe, the IBM MVS/XA operating system and the software AG Adabas data base management system.

2.5 Air Force

Analyzer for Soviet Space Launches Built

An expert software system to analyze the purpose of Soviet space launches will be operational in three years and now exists in prototype form, Capt. Gregory E. Swietek of the Air Force Systems Command has told a San Jose, Calif. seminar.

Swietek spoke to a conference on "Expert Systems."

Work on the expert system was done at Rome Air Development Center, Griffiss AFB, N.Y. The 750-rule software program follows rules devised by expert intelligence analysts to determine whether the launch is an anti-satellite launch, a military payload or a commercial launch. The prototype is now classified due to the types of intelligence inputs it uses.

The system uses information on the status of the current threat and knowledge of Soviet doctrine to provide a hypothesis as to the purpose of

the launch. Such a conclusion must be made quickly, due to the possibility that it is a hostile launch. The system only assists a human analyst, rather than replaces the analyst. It is considered low-level decision-making.

Swietek said there is an "ambitious" development plan to complete the prototype. Users, all members of the intelligence community, have received a demonstration and were impressed, he said.

Rome Air Development Center is also developing software development tools using artificial intelligence techniques. Some of the first products will be completed in Fiscal 1988, Swietek said. "We're not looking to replace the software professional. What we're looking to do is take away the more mundane and boring aspects of his job," he said.

Swietek also spoke on the Pilot's Associate artificial intelligence program headed by the Defense Advanced Research Projects Agency. Contracts to develop expert systems to aid the pilot were awarded to competing teams headed by McDonnell Douglas and Lockheed. "We're not developing AI to get the pilot out of the cockpit. We don't really feel AI is going to be ready, ever, to handle all the diverse situations a pilot is going to be faced with," Swietek said. "We are looking to reduce the workload on the pilot significantly."

A pilot's associate expert system will be able to detect the most important information and give that to the pilot, suppressing unimportant

detail, he said. Swietek emphasized the Pilot's Associate program is a demonstration program. A final demonstration is scheduled for 1990.

At present, there is no hardware that can run expert system software in real time. When it is developed, perhaps in two or three years, it must still be militarized and sized for small systems such as missiles.

"AI is a very nice thing to do now in the university community and in the commercial markets. But for the Air Force to buy a system it has to own for 20-25 years, we have to have a better idea of standards (for): inference engines, knowledge bases, maintenance issues and documentation, languages, hardware and testing."

Swietek said there is $50 million in Air Force AI-related funding in Fiscal Year 1986. "Right now, we are riding a crest of high expectations. But I don't believe my senior management is going to accept a lack of a product in the field that much longer. We need strong demonstrations in two or three years. Otherwise," he warned private industry, "we have a strong chance of seeing the excitement about AI dry up again."

2.6 Air Force

Expert System to Avoid Missiles

The Air Force has called for proposals for an artificial intelligence expert system to advise military pilots on avoiding imminent enemy threats.

Charles Wagner, focal point at the Air Force Wright Aeronautical Laboratory for the project at Wright-Patterson AFB said the effort is not related to the Pilot's Associate Program of the Defense Advanced Research Projects Agency. It applies to all types of military aircraft.

Called the Threat Expert Analysis Systems (TEAS), it will rank the threats by priority and suggest solutions, but does not assume actual control of the aircraft, Wagner said. The system must be capable of displaying the reasons for its decisions. Recommendations can include a change in altitude or direction, use of chaff or flares, use of electronic counter-measures, use of weapons or evasive maneuvers. For example, the system may recommend use of low-level flight to use terrain to mask the aircraft from enemy radar.

Contractors must develop software to provide a response or combination of responses for a particular threat situation, build a knowledge base about threats, demonstrate TEAS in a laboratory and generate candidate architectures for future use.

The TEAS program will be given inputs such as terrain elevation, aircraft status, a route plan, threat types including briefed threats and current threat data from on board sensors. If an air-to-air threat is assumed, the assumption should be made that the aircraft will attack.

Selection of one or more contractors will be based on a scientific and engineering evaluation of the proposal. Cost is second in priority. Wagner

said he did not want to give estimates of the cash value of the award, but added it involves eight man-years of labor.

The software will be in Common LISP or FORTRAN, and run on a DEC VAX/VMS environment.

2.7 Air Force

TEMPLAR Has Wide Defense Dept. Applications

TEMPLAR, the Tactical Expert Mission Planner system being developed by the Air Force using artificial intelligence, has been described to the Naval Research Advisory Committee during a meeting at Woods Hole, Mass., as having greater application throughout the Defense Dept.

Capt. Pete Priest of the Rome Air Development Center told a special panel of the committee on artificial intelligence that the system can assign the use of air resources for the following day in two hours, as opposed to the present 24-hour planning process.

The program can generate a 1,000 sortie air tasking order, the actual order describing aircraft, fuel requirements and targets, in two hours using natural language interfaces and graphics.

Demonstrations are planned in June and October, 1987. The TEMPLAR system will be in use at the annual Blue Flag command and control exercise.

The initial design study began two years ago. Phase one was a six-month, $230,000 effort.

2.8 Air Force

SENTINEL Expert System Aids Command and Control

SENTINEL, an expert system to aid a strategic missile warning officer to evaluate multiple missile launches that may involve 20 countries, has been completed by the Air Force Institute of Technology, Wright-Patterson Air Force Base, Dayton, Ohio.

The system, built to work with a specific command, control and communications network called Simulated C3 Operator Performance Evaluation (SIMCOPE), was built on a Xerox 1108 LISP machine with 40 megabytes of hard disk storage. It was described at a conference in Orlando, Fla. on "Applications of Artificial Intelligence" sponsored by the Society of Photo-Optical Instrumentation Engineers.

SENTINEL was completed in October 1985 and uses 800 rules. The software is Xerox's Harmony version of InterLISP-D, and the Buttress release of the LOOPS expert system building tool, also by Xerox.

The growing complexity of information presented to the strategic missile warning officer makes it essential to reduce the workload. SENTINEL is a blackboard model using rule bases and object oriented programming

techniques that permit it to deal with uncertainty and provide several layers of explanation.

SENTINEL can analyze information from a variety of sources to determine whether a launch event represents a test, a hostile event or an unresolved event. It consolidates information contained in a series of intelligence reports into a few variables, such as an intelligence condition that can be red, green or yellow.

Results with SENTINEL will be applied to further expert system and decision aid development for C3 networks, Air Force officials said. The work was done by Daniel L. Tobat, Steven K. Rogers and Stephen E. Cross.

2.9 Army

Expert System Added to Tactical Display

Symbolics, working with the U.S. Army Armor Center, Fort Knox, Ky. is adding an expert system to its Intelligent Tactical Display, which uses tank icons to monitor fuel, ammo and personnel of each tank on the battlefield. The addition of an expert system that "knows" battle planning, tactics and materials will enable the system to be used in training tank commanders. Commanders can enter a plan of attack into the computer, signal the computer to run the battle, and watch the action unfold. Projected enemy action is also depicted. It was developed by James Richardson of Symbolics and Capt. Bill Johnson of Fort Knox.

2.10 Army

System Assesses Combat Vulnerability

The Army Ballistic Research Laboratory, Aberdeen Proving Ground, Md. is building an expert system called Genie to analyze vulnerability of combat systems to a wide range of threats. The first application will assist human experts in assessing the vulnerability of jet engines. The Genie project was developed in FranzLISP on a Vax 11/750, and is currently running in InterLISP-D on Xerox 1108s. The system can predict whether fragments will penetrate various operating components of the jet engine. In the future it will be applied to other types of weapons systems. Future plans also include running the system on a LISP machine.

2.11 Army

Army Rebids Battle Expert System

Two artificial intelligence contractors have been dismissed by the Army Signals Warfare Center, Warrenton, Va., for lack of progress on an artificial intelligence-based battlefield situation assessment expert system.

The contract is supervised by the Army Communications and Electronics Command Vint Hill Procurement Office, Warrenton, Va. The procurement officer for AISAF (Artificial Intelligence Based Situation Assessment for Intelligence Fusion) is Warren Schaeffer.

The contract is valued at 11,400 hours of work. Based on contractor hourly charges, the contract amount could vary from $550,000 to just over $1 million. The contract is funded from the federal budget category known as 6.1, or basic research. Two years of previous work were also funded at the 6.1 level.

The previous contractors, which the Signals Warfare Center would not identify, made enough progress to convince the Army to continue the work. The Center began development of a computer program that would test the new expert system. It is a spatial representation of the Augsburg-Munich area of West Germany. The Center also developed, as part of the effort to test the contractors' battle assessment expert system, a spatial problem solving paradigm which will be used with the Augsburg-Munich map.

The AISAF software will be domain independent and extensible. It is domain independent only if it can assess a tactical situation accurately regardless terrain, such as jungle, desert or arctic tundra. It is extensible if it can accurately assess a tactical situation no matter what the enemy's force type, mix or quantities of equipment and personnel.

"That is," the request for proposals states, "the paradigm should be capable of accurate situation assessment whether assessing the tactics of

First Century Roman Legions or Twenty-First Century °Star Wars' equipment and forces."

An effort was made by the previous contractors in Fiscal Year 1984 to implement a small portion of the AISAF paradigm, using FORTRAN and FranzLISP languages. By the second quarter of FY 1984, it was recognized that the AISAF effort consists of two logical and functionally distinct processes: a situation hypothesis generator and a spatial problem solver or situation hypothesis tester.

The FY 85 contract is aimed at correcting weaknesses. The situation assessment will then be compared to the known order of battle and evaluated in terms of terrain, weather conditions, enemy positions and threat potential. The test plan calls for changing those factors and running the simulated battle again. A final scientific report, available to other contractors, will detail the results and that portion of the AISAF implemented for testing.

The next contractor will be assigned three tasks: analyze the existing AISAF program, improve it and thoroughly document it. Documentation will include written proof that the improved AISAF is domain independent and extensible. Work will be completed by Dec. 31, 1988.

AISAF must be compatible with DEC VAX 11/750 or 11/780 hardware. Those computers are connected, via an RS-232 port, to a XEROX 1108-105 workstation. A technical library is available by calling Douglas Chubb at 703-347-6445.

2.12 AT&T

AT&T Puts Artificial Intelligence Engine on Chip

AT&T Bell Laboratories has developed a fuzzy-logic inference engine for dealing with uncertainty and approximate reasoning and is in the process of fabricating it on a very large scale integration chip.

Early testing indicates it will meet its primary goals, Bell scientists told the IEEE Second Conference on Artificial Intelligence Applications in Miami Beach.

Potential applications include decision making in command and control and intelligent robot systems. Fuzzy logic is the point at which an expert system runs out of hard and fast rules that usually result in correct answers. It occurs when an expert system sees a situation, for example, not encountered by the human expert whose knowledge has been captured in the expert system. Often the human expert's knowledge is uncertain or imprecise.

The mask layout of the inference engine chip has been completed. Timing simulation suggests the engine can perform 80,000 FLIPS (Fuzzy Logical Inferences Per Second).

Fuzzy logic use is not new, and has been incorporated in several systems, Bell scientists M. Togai and H. Watanabe told the Miami Beach conference. One example they cited is CATS, a diesel locomotive diagnosis system that uses 530 rules and will soon be expanded to 1,200.

Fuzzy inference has been proposed for use in command and control to select the most suitable guidance algorithm for intercepting missiles. Selection is done by considering a constantly changing environment, such as angular positions, accelerations and distances to an enemy missile. ,

The first design for an inference engine on a chip stores 16 expert rules per chip. Rules can be stored using either reprogrammable random access memory, or permanent read only memory.

2.13 Carnegie Federal Systems/Computer Sciences Corp.

SDI, DOD Attracting AI Industry

Two firms have won recent contracts from the Strategic Defense Initiative Organization (SDI) for development of software that can be used to build artificial intelligence computer programs for use in a space-based defense system.

The two are Carnegie Federal Systems, Pittsburgh, and Computer Sciences Corp., Falls Church, Va. Carnegie, a subsidiary of Carnegie Group, is in the midst of a major effort to capture a larger share of the $220

million-per-year federal artificial intelligence business, President and Chief Executive Officer Larry K. Geisel said. Carnegie Group has previously concentrated on industrial applications of artificial intelligence.

Computer Sciences Corp. won an 18-month, $500,000 contract from the Rome Air Development Center, Griffiss AFB, N.Y., to develop a software tool for automating the SDI design process.

The contract was won by the Technology Activity of the Systems Div. Research and development on the "High-Productivity Tool" is already underway.

"This is a very important contract for us," Technology Activity Vice President Dr. Sam Steppel said. "Systems Group recognized the importance of getting in on the ground floor of SDI. As a group, we submitted eight proposals to Rome Air Development Center."

Computer Sciences Corp. project manager Bill Woodward said efforts under the contract will focus on use of SMALLTALK-80 to create an expert system for automation of the design process. SMALLTALK-80 is an object-oriented language well suited for building a software prototype. The new expert system will analyze a structured specification, then create an initial design using design rules.

The work is being done at the Technology Activity's headquarters in Vienna, Va., at the STAR-LAB (Systems/Software Technology Applications and Research Laboratory). STAR-LAB supports work in system and software

engineering tools, artificial intelligence and other advanced technologies. STAR-LAB will soon include an Ada software development laboratory.

Carnegie Group's Geisel said artificial intelligence will become increasingly important in upcoming federal software procurement. In the past, Carnegie has concentrated on expert systems and natural language.

Geisel said Carnegie Federal Systems was involved in $3 million worth of federal artificial intelligence contracts in 1985, and planned to submit 10 proposals for work totaling $8 million in 1986. Geisel is primarily interested in the three largest sources of federal artificial intelligence funding: the Strategic Computer Program funded by the Defense Advanced Research Projects Agency (DARPA), SDI and the National Aeronautics and Space Administration space station. NASA has pledged that there will be one or two operational expert systems on the space station when it is launched in the mid-1990s.

Carnegie Federal Systems has seven people working on artificial intelligence programs, but will add 40 more. Carnegie Federal Systems acquired facilities separate from Carnegie Group in the suburban Virginia area of Washington, D.C., and at the company's headquarters in Pittsburgh.

Carnegie Federal Systems now has a $1 million, two-year contract from the SDI office to develop software tools that can build computer programs for battle management of space-based defensive weapons. It is performing the work in conjunction with Boeing Computer Services. Later phases of the contract call for development of methods to test artificial intelligence

software tools, development of techniques for use of artificial intelligence on parallel computers, and validation of artificial intelligence software to assure it will make the "right" decisions.

Carnegie is also a consultant to TRW under a $500,000, 33-month contract to develop a tactical expert mission planner under a Rome Air Development Center contract. Carnegie will develop a natural language interface for the program, called TEMPLAR. The program can generate plans for Air Force tactical aircraft missions or sorties, according to a description of the system by Air Force Capt. Pete Priest.

One of Carnegie's products used to build expert systems, Knowledge Craft, is already used in artificial intelligence research by DARPA for development of naval battle management techniques. Carnegie Federal Systems will initially concentrate on text processing. Another Carnegie product, Language Craft, is used to develop natural language interfaces.

Carnegie Federal has a $550,000 contract for classified work in which one and two-page messages, received into the computer in electronic form (such as cables) can be searched for small number of subjects of special interest. Carnegie wants the system to read a flow of messages and decide which pertain to the specified subject areas. The systems "understands" the data and then extracts it. The system, called Text Extraction Summarization System (TESS), has obvious value for intelligence work, although Carnegie officials did not identify it as such. A prototype of a test processing system has been in demonstration for a year. There are 15 individuals working on the project.

Future work will concentrate on a number of DARPA, Air Force and NASA areas.

2.14 Defense Advanced Research Projects Agency

DARPA Smart Weapons R&D Starts

Research on a new generation of "smart" weapons carrying "brilliant" submunitions to the battlefield has begun with a briefing to industry on an unmanned, autonomous aircraft that searches out and designates targets.

One possible use is a flying, robot tank killer that patterns its actions after those of an animal that evades capture, stalks its prey and catches it.

Clinton W. Kelly, 3rd, executive director of the Strategic Computing Program in the Defense Advanced Research Projects Agency (DARPA), said the effort will begin Oct. 1, 1986 with three to five study contracts of several hundred thousand dollars each. The program will be expanded in FY 1987.

"It could be useful in its own right, or could carry submunitions," Kelly said. The air platform will take advantage of research accomplishments from another DARPA program, an autonomous land vehicle that has successfully followed a road behind the Martin Marietta plant in

Colorado. Next year the vehicle will be equipped with DARPA-developed parallel computers and navigate autonomously over open terrain. The land vehicle is part of DARPA's Strategic Computing Program.

"It might have the capability for identifying the most likely places to look for enemy armor, given very general, high-level instructions," Kelly said. "If it carried terminally guided submunitions, presumably it could designate targets for these submunitions which would then strike those targets.

"The other part of the program, obviously, is the work on the terminally guided submunitions themselves. In either case, we see the need for the development of a very high-performance architecture -- which would be scalable and modular -- that would provide us with signal-processing capability, symbolic processing capability and numerical processing capability essentially in the same package," he said.

"We need to do image understanding, and that requires both signal processing and higher level symbolic capability. We'll have to give commands to control systems, and in fact do calculations to do firing solutions. That suggests numerical capability. All of these will have to communicate with one another, and that suggests a heterogeneous architecture with these three elements connected on some sort of high-speed bus. They might be somewhat distinct, but able to communicate with one another.

"It would be developed with weight, space and power constraints, consistent with the kinds of missions the aircraft and the terminally guided submunitions might evoke," Kelly said.

Kelly said Defense researchers would like it to be able to evade once its sensors indicate detection by the enemy.

While DARPA officials have discussed only the air weapons platform in connection with the smart weapons program, the technology could also be used in the present M-1 tank to aid the gunner in acquiring targets and aid the driver in navigation, Kelly said.

In other matters, Kelly said he expects to sign three contracts for new-generation computers this month and three more in June. He also said the follow-on vehicle to another DARPA project, a six-legged mechanical walking vehicle, was a technical decision rather than a budget-cut casualty. It may yet survive, he said.

2.15 FMC

Expert System for Gun Maintenance Developed

FMC Corp. has developed a Mark 45 gun mount maintenance advisor based on an expert system. The Mark 45 has 15 major assemblies with 23,000 individual parts. The number of personnel now available to repair it is 18% less than required, with the shortage predicted to increase. The fault

isolation system is based on an interactive dialogue model. Electrical data can be obtained by the system directly from test equipment built into the gun mount itself. Hydraulic and mechanical data is obtained through a question and answer session on a computer screen between the system and the user. The system can pull up schematics from a video disk for presentation to the mechanic.

2.16 FMC

Vehicle "Brain" Avoids Obstacles

FMC Corp. has developed an intelligent pilot for an autonomous vehicle that so far has guided a 10-ton M-113 personnel carrier around obstacles, FMC officials John J. Nitao and Alexandre M. Parodi told the IEEE Second Conference on Artificial Intelligence Applications in Miami Beach.

The FMC intelligent pilot, which uses a sonic imaging system and an expert system, was tested at Camp Roberts, Calif., in March, 1985 and demonstrated obstacle avoidance at 5 mph. Future tests involve higher speeds along an unpaved road utilizing image processing. An inertial navigation system, combined with sensors attached to the tracks of the vehicle to determine speed, provide vehicle position, heading and speed.

The vehicle uses heuristic geometric reasoning and search techniques to process a local map, which is a compression of the local segment of the global route plan. The algorithm runs in real time, allowing its use on

large vehicles. The front-mounted sensor has a range of 33 meters and a frontal view of 120 degrees.

The vehicle moves forward by planning subgoals. Since it has only a forward-looking sensor, it is possible for the pilot map, used to plan the path of the vehicle, to run out of subgoals. At that point it does a pivot turn. It must also use this behavior if it detects obstacles from the left to the right of its field of view.

Prior to field tests the behavior of the vehicle was simulated in a computer. The model was a 10-ton vehicle that could pivot, and included detailed descriptions of its steering and power mechanisms.

2.17 Ford Aerospace

Ford Builds River Crossing Sentry

Ford Aerospace and Communications Corp. is building an expert system that acts as a sentry and reports river crossings by enemy forces. Ford has completed a feasibility demonstration of the system, which can serve as a design for many types of command and control systems. The demonstration combined a Briton-Lee data base machine, a Sun Microsystems workstation and an expert system. It can identify spatial and temporal patterns of enemy activity, alert decision makers and give them projections and alternatives, and execute the response selected to evaluate the success or failure of the

response. Threats are shown graphically. The system was developed by Sharon Storms, Richard Sherman and Michael Bender.

2.18 France

French Exploring Military AI

Although much smaller in scale than the U.S. Defense Advanced Research Project Agency's Strategic Computing program, the French Ministry of Defense is now sponsoring research on a number of potential military applications of advanced electronics and artificial intelligence (AI) technology, according to two recent French publications.

"Electronics and advanced information processing (or 'informatics') are key for everyone, including the military...Because of their importance, the military has launched research on the same microelectronic fundamentals that are also included in Japanese and American research plans," said Engineer General de Saint-Germain, the deputy director of France's Directorate of Research, Studies and Technologies (DRET), the French equivalent of DARPA.

"We want to give France the capacity to produce electronic components more rapidly, more flexibly and at a lower cost," de Saint-Germain told "Autrement" magazine in its October issue on the French armed forces. "We are becoming the catalyst for research that, over the next three or four

years, will improve the performance of our electronic circuits and, more importantly, make us less dependent on foreign sources."

In addition to research on electronic devices, DRET -- the office that coordinates advanced R&D for the Defense Ministry's General Delegation for Armament (DGA) -- is also financing research on military applications for AI. According to the October issue of "La Recherche", DRET-sponsored research includes an effort by the AERO company to develop specialized programming languages for autonomous mobile robots. Midi Robots, located in southern France, is studying the integration of multisensor and navigational systems for autonomous robots.

Robotic vehicle research includes the development of an amphibious remote controlled robot, developed by Assistance Industrielle Dauphinoise, a small start-up company located near Grenoble. Equipped with 6 pairs of wheels and tank treads, the AID robot can climb large obstacles and stairs. The Defense Ministry plans to use a version of the robot to transport dangerous explosives.

Other important DRET-sponsored AI research includes language recognition studies at the Laboratory for Informatics in Mechanics and Engineering Sciences (LIMSI) in Orsay. LIMSI is now working with Crouzet Corp. to develop a vocal command system for aircraft and helicopters. The system, which "Autrement" says can now recognize over 30 words, is being evaluated in a Mirage 2000 flight simulator as well as on a Mirage 3R combat plane. Crouzet is planning operational development on the Mirage 3 in the coming year.

Crouzet also hopes to have a more advanced version of its voice command system included in the joint Franco-German attack helicopter scheduled to go into production in the 1990's. The ultimate goal is a system that will allow a pilot to ask questions about his aircraft's status, with the airplane responding in natural language through a voice synthesizer.

Finally, the Laboratory for Automation and Systems Analysis (LAAS) at the French National Center for Scientific Research (CNRS) in Toulouse, is studying issues of pattern recognition, scene analysis and the integration of AI functions for robotic command systems. Computer vision applications are being studied for mobile ground robots and the analysis of aerial and space imagery. These techniques, already demonstrated by the French National Center for Space Studies (CNES) to analyze U.S. Landsat imagery, could presumably be applied to imagery from the military optical reconnaissance satellite now under consideration by the French government.

2.19 GA Technologies

Expert System Destroys Munitions

A prototype of a chemical munition disposal production line, operated by an expert system, has been built by GA Technologies in San Diego that can reduce the cost of disposal and eliminate hazardous duties for humans.

The production line was described by GA official John F. Follin before the Austin, Tex., conference on "Artificial Intelligence and Robotics for the Army Soldier Support Center."

The system was designed in Common LISP language. The expert system can modify or create rules while it is operating the production line.

In effect, the system is designed to program itself, Follin said. Operator interface is established through touchscreens, voice recognition and keyboards. A voice synthesizer will be used to provide feedback to the operator.

"We will attempt to demonstrate that once the rule-based expert system is operating, it can carry out operations that have not been programmed," Follin said.

GA is developing the system with internal funding. The system will explore the extent to which expert system control of a multi-robot process is feasible. The expert system will have to be compatible with the extensive control software previously written to control the chemical weapons processing cell. Once developed, GA officials expect the control system can be adapted to a variety of control systems that are computer-controlled.

2.20 General Electric UK

GE (UK) Developing AI Tools

The General Electric Co. (UK) is participating in both the British Alvey Program and the European Economic Community's ESPRIT program through major projects in its Hirst Research Center, Wembly, and the Marconi Research Center in Great Baddow.

The work of GEC is reported by the London branch of the U.S. Office of Naval Research in the Navy publication, "European Science Notes," by Dr. J.F. Blackburn, the Commerce Dept. representative assigned to the branch. The purpose of the office is to report European scientific progress to the Navy.

The GEC Software Research Division is exploring expert systems and system shells, knowledge representation and acquisition, machine learning, causal modeling, planning and problem solving, inference, logic programming, cognitive psychology, man-machine interface and the languages of LISP, Prolog and POP.

Under the Alvey Program banner, GEC is developing three projects: a flexible toolkit for building expert systems, a formal requirements specification to develop a method for capturing informal applications concepts, and a software reliability model to certify software products.

GEC participates in an ESPRIT program called "Portable Common Tool Environment" to develop the basic mechanism for a single user workstation used for software production and connected to a local area network. A

second ESPRIT project, called "Application Software Prototype Implementation System," will cover executable specifications, reuse of components, and expert assistants using application domain knowledge.

A wide area network has been completed and demonstrated linking the four main ESPRIT sites, including the Hirst Research Center. Four companies -- GEC, International Computers, Bull and Siemens -- worked on the network. The network is linked to the Science and Engineering Research Council, and the American/European Unix Users Group. The four companies were joined by Olivetti and several smaller groups to establish X.25/Ethernet, which has several thousand users.

Other work by GEC includes the addition of vision and tactile sensing to the GADFLY Manipulator developed at Marconi Research Center, which gives stiff, fast component handling for manufacturing assembly. Hirst Research Center has developed a modular vision system which uses an image-processing language to customize new applications from existing modules. Marconi is processing remote sensing data from synthetic aperture radar systems to identify land features and ocean wave patterns.

2.21 Georgia Tech Research Institute

AI Aids Auto Target Recognizer

A Tactical Expert System (TESS) that reads infrared scenes for automatic target recognition purposes is being developed by the Georgia Tech Research Institute, Atlanta, Ga.

The system was described to an "Applications of Artificial Intelligence" conference sponsored by the Society of Photo-Optical Instrumentation Engineers in Orlando, Fla. Presenting the paper were: John F. Gilmore, Melinda M. Fox, Alicia L. Stevenson and Marla X. Rabin.

TESS is a long-term research project dedicated to improving the interpretation of tactical image scenes through the exploitation of artificial intelligence techniques. Though the paper highlighted automatic target recognition, TESS can exploit multisensor data, intelligence information, target signature data and tactical information sources so that it may function in C3I, high-valued fixed target and threat analysis domains.

TESS was developed using Georgia Tech's Generic Expert System Tool (GEST) on a Symbolics 3670 LISP machine. TESS is being developed to overcome current automatic target recognition deficiencies.

Hughes Aircraft and Martin Marietta Aerospace are independently pursuing contextual target cueing systems which utilize artificial intelligence to exploit global scene information. Martin Marietta Aerospace has approached the goal by designing an information fusion and feedback architecture centered on a production rule system. Hughes Aircraft uses an

object-oriented approach wherein a scene object has the goal of self identification.

GEST provides a rule-based capability which exceeds Martin's production rule approach, and an object-oriented environment corresponding to the Hughes system, the scientists said.

2.22 Gould Electronics

Gould Plans AI Hybrid for ASW

Developing systems that use artificial intelligence (AI) to complement conventional "number crunching" processing, Gould Electronics is planning a research strategy that it hopes will keep its Pentagon clients in the warm and friendly climes of product acceptance -- far from the blasts of another "AI winter."

"Gould looks at AI as a product enhancement," says Terrence Thompson, director of AI research at Gould's Advanced Technology Center in Arlington, Va. Thompson said that Gould will base AI research on its existing work in the field of signal processing for antisubmarine warfare (ASW) to develop "hybrids incorporating numeric and symbolic processing."

Historically, Thompson notes, "Gould machines have been known as very fast number crunchers" used for digital image and signal processing. While such systems do a good job of enhancing known images, Thompson says that

the addition of symbolic processing will allow ASW systems to better deal with "uncertainty, novelty, vagueness and fuzziness."

Such a hybrid, he says, could be used to construct a system that fuses the knowledge of experts in the "...wide array of technologies including meteorology, acoustics and signal processing" utilized by the Navy for ASW. "We want to couple these different domains of knowledge together so that they cooperate and reinforce one another," Thompson says.

Thompson says that the resulting expert "rules of thumb" will "on the first order feed back to augment the results of numeric enhancement." The addition of symbolic AI processing, he says, will allow signal processors to focus on sounds of most interest to sonarmen while filtering out unwanted or extraneous noise and signals.

Gould's new effort to develop AI hybrids, which Thompson characterizes as "a relatively high technical risk area," will be initially focused on systems where "you don't have to beat your opponent 10-1. You can beat him 1.5-1." In addition to ASW sensors, other "smart" applications under study by Gould's 10-person applications staff will include systems to improve torpedo guidance and control as well as collection management equipment for electronic warfare that can better counter techniques used by an enemy to evade detection.

A fourth AI project involves the development of a robotic land vehicle for the Army Tank Command. Unlike the Defense Advanced Research Projects Agency's autonomous land vehicle (ALV) -- which this past summer ran under

its own guidance down a road at a speed of 10 kilometers per hour -- Thompson says that the Gould robotic tank will initially be remotely controlled, with gradually evolving autonomy.

In the development of autonomous vehicles, Thompson says that "the ALV starts on the high ground, while Gould is starting on the low ground." The difference, he explained, lies in DARPA's charter to explore "high risk technologies," while Gould's customer, the Tank Command, "wants a more evolutionary approach that develops systems through a very long life."

This strategy, Thompson indicated, is a result of Gould's experience dealing with operational commands, which he said tend to be less interested in conceptual breakthoughs than in tangible product improvements. "AI is not a technology that's robust enough to replicate the hundreds of man years that have gone into the development of conventional military systems," he says. "Gould's role is not to replace these systems but to augment them." Additional research, he added, will address "a lot of unresolved questions which are best attacked by parallel processing."

2.23 Italy

Italian Firm Develops Military AI

FIAR (Fabbrica Italiana Apparecchiature Radioelettriche), Milan, Itlay, is developing a real-time knowledge-based battle management system for an organization associated with NATO (North Atlantic Treaty Organization).

FIAR is lead company for the project, which was commissioned by the New Technologies Subgroup of the Independent European Programs Group associated with NATO. Also involved in the project are a French, Belgian and Dutch firm, and four British firms. Their work is reported by scientist Paul Roman in "European Science Notes," published by the U.S. Office of Naval Research branch in London.

Current plans call for fusion of land and airborne sensor data. Each nation will adapt a generic design created by the research project to its special needs. Sensor input will be joined and automatically evaluated in real time from data obtained from visual, laser, acoustic, radar, microwave, infrared sensor and infrared imagers. The project is being evaluated for value to U.S. naval battle management.

The project will involve inferential activities such as understanding, reasoning and monitoring. Sensory systems will feed data into a conventional computer-based signal processing unit that has limited intelligence and makes rough evaluation of each data set. The processed data then enters an expert system which tries to understand the meaning of the data. A second expert system "arbitrates" unresolved data from the first system. A third expert system receives chosen solutions and performs reasoning and planning on the new conclusions.

The system uses a central supervisor unit which synchronizes the performance of all the other units and knowledge bases. It acts as an intelligenct clock.

Design of the system is in an early stage. No decision has been made on whether object/attribute techniques or rules/frames devices will be used.

In the U.S., Navy battle management work involving artificial intelligence is under direction of the Defense Advanced Research Projects Agency.

2.24 Northrop

Northrop Expert System Tests F-5

Automated testing of avionics on the F-5 fighter has been performed by the Northrop Corp. Aircraft Div., Hawthorne, Calif., using an expert system called IN-ATE (INtelligent Automatic Test Equipment).

Northrop plans to use IN-ATE to tell maintenance personnel what tests to run with their automatic test equipment, so that the time required to find a fault will be reduced. Eventually, Northrop will place the expert system in the software of their more conventional automatic test equipment. The expert system will evaluate the problem, and order a particular test. It can do this without human assistance. When it has found the fault in an electronic circuit, it will notify the human operator.

Results of the use of IN-ATE were described in a paper by Northrop officials Don Allen and Kirk Rader at the Aerospace Applications of

Artificial Intelligence conference in Dayton. Testing was performed on a printed circuit board from the aircraft's APQ-59 radar, which is an item that can easily be replaced on the flight line without a lengthy trip to the repair shop.

Northrop has been using Lisp IN-ATE on a DEC VAX, but plans to test additional versions it on a Lisp computer especially designed for artificial intelligence research. Additional tests will be made of Micro IN-ATE on the Apple Macintosh and the IBM PC. Pascal IN-ATE will be tested on a DEC VAX. IN-ATE differs from traditional expert systems in that it can generate its own expert rules, making it applicable to a large variety of electronic systems.

2.25 Science Applications

SAI Builds KBS Ship-Tracking System

A team at Science Applications Inc. of McLean, Va., has developed a prototype expert system that models the evaluation criteria used by ocean surveillance analysts to discriminate vessel tracks. The system, developed with internal research and development funds, is now being expanded to handle multiple vessel tracks and weather information.

Team leader Elizabeth Groundwater said the system is currently running on a Symbolics processor, but other processors are being evaluated. "Nobody

is currently using it," she said. "But it can use any kind of sensor input relevant to such surveillance."

She notes that an ocean surveillance watch analyst goes through three evaluation stages in assessing platform and track data. Such assessments are especially complex, given the variegated data that must be fused reliably and quickly to be useful. Thus an analyst must first judge whether a sensor has actually seen a platform or an event of interest, with outputs translated if possible into platform and position identification. AI aids for this initial screening are under study by SAI and other firms, she said, including some which match sensor data against stored libraries.

The second stage correlates position and platform data into coherent tracks of platform movement, an area where problems like platform non-identification, position errors and intersecting tracks occur. Research and development into expert tracker/correlators for such problems is under way at: SAI, which is using a Bayesian probability-based ISATS system, at Naval Ocean Systems Command (NOSC) in San Diego, which has developed a STAMMER tactical situation-assessment system; and at the Navy Center for Applied Research in AI in Washington, D.C.

The last stage analyzes correlated tracks to determine platform missions and arrival times at points of interest in order to alert friendly forces. This stage has seen little work because of the R&D emphasis placed on the first two, although Verac Inc. has addressed intelligent data management and display through its INCA system. The new SAI system addresses third-stage needs, said Groundwater, with its test case being

destination and platform determinations for selected Navy survey ships. This sample allowed the SAI study to be unclassified, while the small number of survey ships, stations and missions involved permitted a one-year development time for the system.

SAI's event-driven system makes new or updated assessments from platform tracks, reading in event information from a scenario file for demonstrations or from a tracker/correlator. It makes and displays its assessment, then cycles back for more data. "This operation is very different from typical expert systems that only derive one assessment from one unchanged input set," she notes. SAI's system has a production-rule architecture that is based on forward chaining and builds assessments forward from sub-assessments that are themselves built from event inputs by production rules. The rules access five knowledge sources: platform deployment history, survey ship relief posture, other ships' activities and the ship's own movement, with a "multimission resolution" knowledge base then combining and weighing the resulting composite evidence of destinations and missions. Here time is a major factor, since the weighting of knowledge sources changes markedly during survey-ship cruises.

SAI relied heavily on professional watch analysts in iterative comparisons of heuristic "rules of thumb" with the system's newly embedded production rules. SAI is aiming at multi-platform models featuring portability, interconnectivity and distributed processing (useful for aircraft assessment).

2.26 Sandia National Laboratories

Security Robots Lead Sandia Work

Sandia National Laboratories is under continuing pressure from the Energy Dept. and the Defense Dept. to develop artificial intelligence software for autonomous robots that can act as security guards at sensitive facilities, said L. Byron Dean, an AI specialist in the Future Options Group at Sandia.

Some Sandia officials are concerned that the laboratory is being urged to become a manufacturing facility for the robots, once a technical base of research is completed. Such a move, they warn, would detract from the research function of Sandia.

"We've been inundated with requests," Dean said. A primary purpose of the robots is the protection of nuclear weapons. Concern about potential terrorist actions is behind the requests, officials said.

Autonomous vehicles, such as robots, and smart munitions are the two areas of greatest interest for Sandia AI researchers. Expert systems offer the chance to reduce the circle of error for delivery of nuclear weapons to zero, Sandia officials said in a recent interview. It could also be used for conventional weapons. For example, neutron bombs might never have been developed if expert systems could assure a direct hit on enemy tanks every time a shell is fired. Expert systems could track targets and point fixed weapons such as artillery.

Sandia is also one of the leading laboratories in the nation for the development of AI computer-aided design and computer-aided manufacturing software to integrate weapons design and production. Other systems under development include use of AI to design cables, connectors and fiber optic circuits. There is also interest in intelligence fusion, or the use of an expert system to unify and interpret information from battlefield or spaceborne sensors.

2.27 Martin Marietta

Expert System Improves Computer Vision

Martin Marietta, Orlando, Fla. has developed an expert system that improves computer vision through threshold adjustment and segmented region merging. The system detects tanks and other targets and draws white borders around them to deliniate targets from vegetation or animals. A paper on the system was presented to the IEEE AI Conference in late 1985 in Miami, Fla.

2.28 MITRE

One-Year Army AI Field Test Ends

MITRE Corp. has gained important insight into the implementation of artificial intelligence into an active Army unit during a one-year experiment for the Defense Advanced Research Projects Agency.

Ari S. Zymelman, of MITRE, said the major lesson learned concerned when and how to approach the user. Originally, MITRE had intended to take their expert system called ANALYST, which performs tactical battlefield analysis, into the field to improve it. MITRE was to take the system to a garrison location and improve the knowledge base. Due to a change in the original test site, MITRE instead was tasked to attempt to use ANALYST operationally.

Zymelman said the experiment was influenced by the stage of development of ANALYST, which needed a better user interface. However, taking an incomplete expert system into the field allowed for more productive development work, since the scientists could talk with users.

"At the same time, one cannot approach the users with a blank machine and ask them to fill in their knowledge," Zymelman said in a report on the experiment's results. "They need a straw man to respond to, and with which to focus their attention. Otherwise, they do not seem to have the incentive. It is better to present them with something inadequate than with nothing at all."

Zymelman said he got an intuition from the experiment that the knowledge engineer cannot be replaced, at least in the initial construction of the knowledge base, with an automated software package. Although Army

personnel in the experiment were bright and well educated, they needed the knowledge engineer to help them articulate their expertise. MITRE dropped efforts to capture the knowledge of poorly-educated, lower-ranking enlisted personnel who could perform their jobs better than officers but could not articulate what they do that makes them experts. Major changes were made to the software as a result of the experiment.

2.29 Navy

Robot Sub That Uses AI Completes 40 Dives

The Navy has completed 40 dives with its Advanced Unmanned Search System robotic submarine, which utilizes expert system programming techniques. Comunication with the search vehicle is through an acoustic ultrasonic, slow data rate link. It has an endurance of eight hours and searches at speeds of 5 kt. The Navy is also developing an Advanced Tether Vehicle robotic submarine with manipulator arms for performing work, and a long-range robotic sub that can navigate to an enemy port to perform surveillance or lay mines.

2.30 National Aeronautics and Space Administration

NASA AI System Monitors Aircraft

(This system is included under military expert systems because it has military applications.)

NASA Ames Research Center and Dryden Flight Research Facility are developing a testbed expert system to monitor the health and status of the flight control system of a research aircraft, NASA official Victoria A. Regenie said.

The project, well underway, is divided into several phases.

---In phase one an off-line experimental demonstration system with a knowledge base characterizing a representative aircraft system will be constructed. Phase one also includes the development of a knowledge acquisition tool called KAT that aids in the development of a knowledge base.

---In phase two the expert system will be used with a pilot flying a flight simulator to verify and validate the expert system.

---In phase three the expert system will be used as an assistant to a flight engineer during an actual mission.

---Phase four will link the system with a research aircraft using uplinks and downlinks.

Regenie said KAT is 50-70% complete, while the knowledge base is 70% complete. The system requires 1,000 rules, and is being developed on a DEC

VAX 11/750. She did not use an expert system shell to develop the Experimental Expert System Flight Status Monitor, as it is called. Regenie just acquired a Texas Instruments Explorer, and is getting an LMI machine in the future. Common LISP was used as the development language.

"We don't know the memory requirements," Regenie said. "We just keep piling things in and hope it works."

2.31 Systran

Pilot Aid Expert System Offers Important Lessons

The demonstration at Wright-Patterson AFB, of an Expert System Pilot Aid, built by Systran Corp., Dayton, is providing important lessons for the future Pilot's Associate program sponsored by the Defense Advanced Research Projects Agency (DARPA).

The most important findings are that experts systems for aircraft avionics systems appear to be too slow and too difficult to connect to the rest of the aircraft system. Systran officials said it may be better to do research with artificial intelligence expert systems, and then convert them to Ada language, the more conventional computer language preferred by the Pentagon.

The Pilot Aid program, under which Systran won its contract, is sponsored by the Small Business Innovative Research program and the Air

Force Avionics Laboratory at Wright-Patterson AFB, Dayton. The DARPA program will build on the work done there.

Systran research engineer Richard E. Feldmann said the Expert System Pilot Aid program, based on the F-16 fighter, gives his firm the expertise needed to join a prime contractor for the Pilot's Associate program.

(Texas Instrument's Emergency Procedures Expert System is forerunner to a system that can monitor aircraft sensors, respond to alarm systems, evaluate fast-changing emergency situations, display recommendations and assume control of the aircraft if the pilot is incapacitated. Situations it can respond to include loss of canopy, main generator failure, towershaft failure (which means the accessory gear box shaft from the main engine would break, damaging hydraulics, the generator and fuel pump), hydraulic system failure and smoke or fumes in the cockpit.)

Feldmann said Systran chose OPS-5 as the language for its expert system after evaluating Ross, Hearsay 3 and Rosie languages. OPS-5 was written and is supported by Carnegie Mellon University, Pittsburgh. It is a rule-based production language. Feldmann said its two major shortcomings, the inability to handle time and interrupts, can easily be overcome.

There are no plans as yet to test the Expert System Pilot Aid in an aircraft. Site of the first demo for the Air Force was the Avionic System Analysis and Integration Lab simulation facility at Wright-Patterson AFB. The lab uses a DEC-10 processor connected to a simulation cockpit with an advanced avionics display system and out-the-window Evans and Sutherland

displays. Systran was asked by the Air Force to make some changes that would add realism.

The Heuristic OPS-5 solutions are installed on a Symbolics 3600 artificial intelligence computer, and will interface with the deterministic algorithms on the DEC-10. A voice system is connected to the 3600, and to the pilot's head set and microphones. Thus, the F-16 qualified pilots used in the simulator tests will be able to give and receive verbal information. A mixer will be provided to allow the Expert System Pilot Aid to give priority control to its messages.

The long-term prognosis for artificial intelligence in an aircraft cockpit is good, Feldmann said he believes.

"I see no brick walls ahead of us. There is a need for a lot of planning. I can't say whether it (expert systems in aircraft) is five years or 10 years down the pike," Feldmann said.

"I see the opportunity to use lessons learned in expert systems research for programs written in a more conventional language, such as Ada. The research could be done in expert system language, since it is not a traditional program, but could then be converted to a more traditional language.

"For avionics applications of expert systems there are two things missing: speed and an interface to the rest of the aircraft (electronics system) bus," Feldmann said.

Speed is perhaps the major shortcoming of the Systran Expert System Pilot Aid, Feldmann said. There are three aspects to the Pilot Aid, he explained: engine failure, landing gear malfunction and systems failure on takeoff. The Expert System Pilot Aid does a great job of noticing the engine has failed immediately, but it takes 30 seconds for it to recommend the nearest airport for an emergency landing.

Systran started work on the systems-failure-on-takeoff portion of the Pilot Aid, but ran out of both time and money to complete it, Feldmann said.

2.32 Tennessee Space Institute

System Built to Diagnose Aircraft Electrical Systems

An expert system to help aircraft pilots monitor, analyze and diagnose faults calles FLES (Flight Expert System) has been developed by the Knowledge Engineering Laboratory of the University of Tennessee Space Institute. It can perform analysis of electrical system faults.

2.33 Texas Instruments

FRESH Praised After Pacific Test

Defense and industry experts say they have high hopes for the Force Requirements Expert System (FRESH), the first prototype of which was tested successfully at the Navy's Pacific Fleet Headquarters in mid-1986.

FRESH, a naval battle management computer, helps planners set priorities and make new plans when warships are disabled. The system, built by Texas Instruments, is a cornerstone of the Strategic Computing Program, administered by the Defense Advance Research Projects Agency.

"We're happy with what we are getting," said Chuck Deleot, a Civil Service command and control architect who oversees the FRESH program for the Pacific Fleet. FRESH keeps track of ship readiness status and can reassign ship resources to accomplish a given mission.

2.34 Texas Instruments

TI Demos Army Battle Management

Texas Instruments has completed a two-month demonstration at Ft. Knox, Ky., of an Army battlefield management system which allows tank commanders to know their own location and that of the enemy without leaving the tank.

The system automatically collects information from individual tanks and scout vehicles, and then distributes it to commanders and supply officers. The menu-driven system accomodates several computers, each with a touch-screen display.

Data is collected from three sources: direct inputs from tank commanders; automatic updates from the tank's sensors; and inputs from other tanks in the platoon. The remote integrated sensor includes a laser rangefinder, a daylight TV, a thermal imaging system and a navigation system. The information is placed in a continually updated data bank. Tank and front-line commanders are freed from sending repetitive, lengthy reports to the rear.

Tank commanders can see an electronic situation map and a command menu. The map can be made to indicate contours, land features, tank direction, vehicle routes and route coordinates.

The tank commander also has menus which allow him to enter surveillance information and execute commands. The menus include tactical information, navigation, planning and command and control.

The failure or destruction of one vehicle does not destroy the system. TI developed the system over two years using internal funds.

Chapter Three

Space Expert Systems

3.1 Air Force

Artificial Intelligence Sought to Plan Air Force Space fleet

Air Force Space Division officials in Los Angeles have asked the artificial intelligence community for a "no holds barred" approach in developing an expert computer system called AIM that will plan the military space transportation system of 1995-2010.

Industry representatives have been briefed on the project by Air Force Col. Bill Wittress. Work will be split into two phases: proof of concept and full scale development.

Air Force officials hope to involve a broad spectrum in seeking solutions, and to encourage teaming arrangements. They have asked that the program be exceptionally user friendly, employ a natural language interface and advanced graphics. The system will be used by systems engineers, middle managers and upper managers. Many will have limited proficiency in using computers.

In effect, AIM will be required to design a total "space force" including vehicle use, payload planning and required support.

Space transportation architectures, which include all elements involved in meeting space transportation needs, are currently done manually. It is a laborious, time-consuming process which has become unworkable given the large number of components which will be identified in future joint Air Force/NASA/Strategic Defense Initiative studies.

In late 1984 the Air Force recognized the need for computerized planning of future space transportation needs, and began work on a system called STEAM (Space Transportable Effectiveness Assessment Model). It is completed, but Air Force officials already see possibilities where it could be improved through use of the new programming technique called expert systems. Such systems capture the knowledge of a human expert, and apply that expertise to new problems.

STEAM aids decision making in evaluating space transportation systems. Inputs to the computer program include transportation characteristics, mission and traffic parameters, and associated costs, labor, schedule and risk data. The answers STEAM provides consist of economic analyses, cost/development impacts, risk, uncertainty, complete space transportation architectures, as well as assumptions used in its analysis.

Three areas of the most difficult tasks appear to be amenable to expert systems technology. They are: optimal breakdown of modular space systems

into individual payloads, the optimal manifesting of these payloads onto available launch vehicle systems, and the tailoring of available launch vehicle classes to accept identified payloads. A natural language interface is considered essential to the success of AIM. Other devices, such as a mouse, pull-down or pop-up menus, overlapping windows, icons and other graphics may also be essential.

"There are undoubtedly other areas in which general AI techniques may be applied to this problem," the Air Force said in a briefing paper on AIM in 1985. "The Air Force recognizes that the AI community represents a board group of disciplines which are undergoing evolutionary and revolutionary change on a daily basis. We'd like the AI community to take a °no holds barred' approach to this difficult technical problem."

The difference between STEAM and AIM can be seen in the way payload manifesting is done. The STEAM user selects launch systems from a list of compatible systems as determined by STEAM. AIM must choose an optimal manifesting system by itself.

3.2 Air Force

Artificial Intelligence to Aid Satellites in Orbit

Startup of a program to develop an artificial intelligence (expert system) called Autonomous Satellite Control, allowing satellites to operate

on their own for up to 30 days, has been proposed by the Space Technology Center, Kirtland Air Force Base.

The software, carried onboard a communications, navigation or reconnaissance satellite, will allow fine tuning of orbital parameters to maintain orbit, recharge batteries and perform other routine tasks that now require ground controllers. Controllers will then be freed from routine tasks and be allowed to concentrate on operational missions for the satellite. Such operations could be conducted by one controller operating from a mobile van. A prototype will be tested aboard a satellite by 1995.

All satellites are now controlled from a small number of sites, making them easy targets in time of war, and subject to terrorist attacks in peacetime.

Assisting in the project will be Capt. Robert J. Millar, technical advisor to the Information Support Office, who specialized in artificial intelligence in graduate school at the Air Force Institute of Technology, Wright-Patterson Air Force Base.

He developed an expert system called MPlanner, or mission planner, that is used to develop cruise missile missions. The program is expected to be used operationally, given the success of the prototype. The software develops the best strategic route, including one that avoids air defenses, once the launch coordinates and target coordinates have been supplied.

3.3 Barrios Technology

NASA to Use Artificial Intelligence for Flight Analysis

ESFAS (Expert system for the Flight Analysis System) has been created by Chris Culbert and Lui Wang of Johnson Space Center, Houston, and Harvey Flinn of Barrios Technology Inc. It acts as a front end to the Flight Analysis System, a more conventional software planning program, used by the National Aeronautics and Space Administration. The Flight Analysis System requires a high level of user expertise, but ESFAS can make its operation simple. ESFAS was built on a Symbolics computer using ART from Inference as the expert system building tool. The Flight Analysis System is a complex set of interrelated processors with varied capabilities. The Flight Design System was used to plan several space shuttle flights. ESFAS was written in only five months and contains 100 rules.

3.4 Boeing

Boeing Builds Space Station Expert Systems

Boeing Aerospace Co., Seattle, has developed two expert systems: the Environmental Control Expert System in Space (ECESIS) to control life-support systems on a space station; and the Autonomous Electrical Subsystems Operational (AESOP) which monitors, diagnoses and controls the space station electrical system. Both run on a Symbolics 3600 computer. The man-machine interface for ECESIS is a simple dump of text into a file,

while the AESOP systems shows power system parameters on color-coded, stacked bar charts. Color also indicates component state of health. Icons are used to request detailed component information.

3.5 Contel-Spacecom

Expert System Will Maintain Orbit

Contel-Spacecom, Gaithersburg, Md., working with General Research, is developing an expert system that can aid in maintaining the orbital position of the Tracking and Data Relay Satellite used by the space shuttle.

Once completed, it could be used on other satellites. Specifically, it can guide a satellite controller through a maneuver required to maintain the proper East-West orientation of the satellite. Upcoming steps in development include linking it to a tracking and data relay satellite simulator.

The system was built with the expert system shell, TIMM (The Intelligent Machine Model), by General Research. The system, a computer program driven by rules supplied by a human expert, uses 60 rules.

Spacecom officials said it took three months to get their engineers to believe in the expert system, and supply their expert knowledge, in the

form of rules. Now, an official said, the system has won the confidence of the engineers.

"At first we couldn't get them to supply their rules. Now, we can't get them to stop," an official said. An expert system promises to aid with a current shortage of satellite controllers. The system is called Telemetry and Command Expert System.

The system guides controllers through maneuver steps, watches for errors, manages thruster temperatures, monitors gyro performance, informs the controller of what is happening and recommends steps to follow.

3.6 Ford Aerospace

MARS to Schedule Space Shuttle Missions

MARS, an expert system by Ford Aerospace and Communications Corp., Houston, is designed to schedule the resources needed for each space shuttle mission. Resources include manpower, computers, control rooms, simulators and communications equipment. The Management Analysis Resource Scheduler (MARS) was built using ART by Inference as the expert system building tool. It can spot potential problems in planning future missions.

3.7 Ford Aerospace

Ford Adapting Expert Systems

The Ford Aerospace Space Missions Group, College Park, Md. considers expert systems a relatively mature technology that is now a standard tool of any system development, Group supervisor Allan Jaworski told the AIAA/NASA Symposium on Automation, Robotics and Advanced Computing in Washington, D.C.

"The costs of staffing the space telescope control center could be reduced 60% with expert systems. They could also be used to schedule real time experiments on the space station," Jaworski said.

Over 20 expert systems and artificial intelligence tools are under development at Ford Aerospace for military and commercial missions. Main marketing targets are ground-based command and control functions for the space shuttle, the space station and satellites. Projects include: advanced ground segment, resource planning and management system, automated satellite anomaly resolution and element set correction assistant.

The advanced ground segment is an experimental implementation of a payload operations control center architecture, which is an extension of design concepts used for the space telescope operation control center. Resource planning and management system is an OPS-5 based scheduler for space shuttle operations. The automated satellite anomaly resolution automates fault diagnosis and recommends corrective action. The element set correction assistant (see below), written in Lisp, updates data for the NORAD Space Surveillance Center, which must keep track of all orbiting

objects. The center now has applications programs to perform the task, but it fails for 50 satellites a day. A trained expert must then apply rules of thumb to correct the data base.

3.8 Ford Aerospace

Ford Develops Orbital Analyst

Ford Aerospace and Communications, Colorado Springs, has demonstrated an orbital analyst assistant expert system to the Air Force Space Command that automatically updates database information after reading tracking sensors.

Don Turner, principle investigator for expert systems, said the data shows where orbiting objects actually are, compared to computer predictions of those orbits. The expert system is called Element Set Correction Assistant Prototype (ESCAP) and pronounced "escape." The Air Force has computer models of orbiting objects, but they are not perfect and must be updated with actual sensor data, Turner said.

An expert system uses a set or rules, devised by a human expert, to control actions of a computer. The computer can then perform as a human expert on tasks requiring a short period of time, from a few minutes to a few hours.

The Air Force has no plans to purchase the Ford system, but marketing efforts to other interested parties are continuing. ESCAP has 100 rules and was written in YAPS devised by University of Maryland graduate student Liz Allen (301-454-4251). University of Maryland official Rand Waltzman, of the Center for Automation Research, said YAPS stands for Yet Another Production System. It consists of many of the features of OPS5, an expert system building tool, with extensions to that tool written by Allen.

3.9 GHG Corp.

AI Used for Shuttle Training

An artificial intelligence expert system called VALEX is nearing operational use at Johnson Space Center (JSC) to validate software used for shuttle crew training.

With 500,000 variable data items to enter for each flight, errors in software are common and waste 5,000 computer hours a year. With shuttle flights planned to reach a maximum of one every two weeks, there is little time to debug the software and still give each crew adequate training without VALEX, an automatic error catching system.

VALEX can be compared to software now appearing on the personal computer market that catches spelling errors as soon as the word is typed. Instead of catching spelling errors, VALEX discovers that a programmer has entered the wrong wind profile for winds common to the launch area,

inaccurate launch weight, the wrong launch pad number or even launch site. Errors include recording the launch site as Florida when it is California.

Often the software, called a "load," is sent to the JSC Shuttle Mission Simulator with few errors. Other times there will be numerous errors, requiring the crew to stop training while the software is debugged.

Roger A. Burke, an aerospace technician at JSC's Shuttle Mission Simulator, said the system was perfected by GHG Corp., Houston, a contractor working for NASA. The cost of the prototype VALEX, which catches errors in software that trains the crew for the launch phase of a mission, was $75,000. For launch, on-orbit operations and descent, the system will cost $250,000; the system will save 5,000 computer hours a year valued at $50 million, Burke said.

A typical software "load" for a mission requires five million lines of code, Burke said. It is run on four 10-year-old Univac 1144 computers. The computers lack the capacity to run the simulation and also run VALEX, which stands for Validate Expert System; Burke hopes to purchase a Sun 3 workstation where VALEX can reside to monitor the simulation.

When a trajectory of the simulated space shuttle appears off, VALEX will instantly tell operators why: the weight of the shuttle could have been entered in error, for example. VALEX will then tell operators where in the five million lines of code the error lies.

VALEX operates by following rules, similar to those used by a human expert, to determine the problem. VALEX has 850 production rules (but will grow), and was written with Rulemaster, a product by Radian, Austin, Tex. VALEX took three months to write. It is written in C but GHG has an automatic translator that will convert it to Ada. VALEX will be used in Ada at the Shuttle Mission Simulator at JSC's building Five.

Burke adopted the machine learning approach for the expert system, which is also known as automated concept learning. A new problem can be explained to the system, and it will recognize that problem from then on.

Burke criticized what he calls the "shake and bake" system in which an expert talks to a knowledge engineer, describing what the expert does, and allows the knowledge engineer to develop rules used by software called an inference engine. The knowledge, rules and inference engine are, in Burke's words, then thrown together and shaken up to see what might result.

Separate software is needed for each mission, due to such variables as weight, wind conditions, and payload.

3.10 Harris Corp.

Shuttle Preparation Aided by AI

Harris Corp. has developed a prototype expert system to divide limited amounts of equipment and other items among space shuttle flights.

The system, developed under a contract with Kennedy Space Center (KSC), Fla. is named PEGASUS (Prototype Expert Ground Analysis and Scheduler with User Support). It uses OPS5 developed by Carnegie-Mellon as its basic inference engine, and LISP.

PEGASUS was explained by Robert A. Gargan Jr. and Vincent Kovarik Jr. of the Harris Corp. GISD Software Operation at ROBEXS '86, a conference on robotics and expert systems at Johnson Space Center, Houston.

Kennedy ground technicians have been faced so far with the time-consuming job of deciding which items from a common resource pool should be given to specific flights, with only limited help for that task from computers.

PEGASUS sets priorities on items for shuttle missions by scoring each possibility for tasks assigned to it.

3.11 IBM Federal Systems

IBM Designs Expert System for Shuttle Ground Control

FLIGHT CONTROLLER, an expert system developed by Fred Highland of IBM Federal Systems, Houston (he has since moved to IBM, Gaithersburg, Md.) is designed for real-time space shuttle ground control. It is intended for diagnostic consultation for actions that need to be taken based on reports

of the status of the space shuttle navigation systems. The system gathers its information from displayable data. The system also generates explanations for its recommendations.

3.12 Inference

Inference Develops Diagnosis for JSC Lab Equipment

Mark C. Maletz of Inference Corp., who is based at Johnson Space Center, Houston, is working on an expert system to aid in diagnosis of hardware faults in the Systems Engineering Lab of Johnson Space Center. The lab runs space shuttle simulations for crew training and shuttle mission evaluation. The system is being developed using ART (Automated Reasoning Tool) sold by Inference. Fault diagnosis is done only at the circuit board level, rather than at the component level. Circuit boards with detected faults are pulled and sent to other laboratories at the center for repair. The boards targeted for testing are contained in four high-performance computers used to drive the shuttle simulator.

3.13 Inference

Artificial Intelligence to Automate NASA Software

NASA and Inference Corp., Los Angeles, maker of an expert system building tool called ART, are working together to demonstrate concepts of a software automation workstation.

A requirements language is used to support a very restrictive syntax for a narrow application domain (NASA's flight design software), Inference official Dale A. Prouty told a meeting at Johnson Space Center, Houston. Prouty submitted a paper on the workstation during a meeting called ROBEXS '86, concerning robotics and expert systems for space applications.

The initial specification language consists of a graphical-flow language. The code implementation of the workstation is directly in FORTRAN. The workstation supports automatic handling of all routine interfacing and executable module linking. For demonstration purposes the "workstation shell" is utilized by the design team of knowledge engineers to build shell customization for NASA flight design engineers.

The workstation is targeted at improving software reusability. The approach integrates expert system technology and software reusability principles in a hybrid reuse system. It encompasses both reuse of building blocks of existing subroutines and transformational capabilities to generate code in FORTRAN, Prouty said. It is being developed on the Symbolics AI machine with ART.

The project will be completed in two years.

Designs of software developed are catalogued or classified for reuse in later design efforts. Software reuse is not a new theme, Prouty said. The workstation builds on past research on the reuse of software, first through a requirements language. The requirements language allows workstation interactions to proceed from engineering requirements. Second, it builds on past research by supporting customizations of a general purpose shell for specific problem domains.

3.14 LinCom

Space Rendezvous Expert System Uses HIPO

An expert system to automate rendezvous of space vehicles draws on a software design technique previously abandoned by the computer industry called "Hierarchy, plus Input Process and Output" (HIPO).

The system is called RENEX and was described in a prize-winning paper presented to the ROBEXS '86 conference on robotics and expert systems at Johnson Space Center June 4-6, 1985. The paper was presented by Daniel C. Bochsler of LinCom Corp., located across NASA Route 1 from the space center south of Houston, and Mary Ann Goodwin of NASA's Johnson Space Center.

RENEX is being developed by Johnson Space Center's Mission Planning and Analysis Division. The system has been designed and is currently being coded from HIPO design specifications.

HIPO was developed by the computer industry long ago to graphically display what a system or program does and what data it uses and creates. It was abandoned because it requires large amounts of artwork that are difficult to produce, and are unlikely to be updated and maintained. "These problems, though," Bochsler wrote, "are [now] overcome by technology provided by...the Apple MacIntosh and the Apple MacDraw software where artwork is easy to produce and maintain."

LinCom, a small firm which has done a great deal of artificial intelligence work for NASA, reached these conclusions about expert system software development during design of RENEX:

---Traditional programming development methods can be adapted and refined for software development that includes expert systems. RENEX developers recommend refinement of traditional development methods to include expert systems as part of a "composite software engineering" process.

---Supplements to traditional methods must be developed to aid the knowledge engineering process.

---Knowledge engineering activities must be consistent with the level of detail required at different stages of development. High level knowledge engineering supports requirement phases and detailed knowledge engineering supports design phases.

---Program development can be partitioned so that some areas of detailed knowledge engineering can occur simultaneously with implementatior in other areas.

The expert system, which will be used for ground pre-mission planning, ground real-time planning and monitoring, and onboard planning and monitoring, is being built on a Symbolics 3670 using the ART expert system shell from Inference. The guidance, navigation, and control flight software functions are performed by an existing software package, the Orbital Operations Simulator. It sends relative motion data to an Interactive Machines Inc. 500 to provide animated graphics of on-orbit motion between the active vehicle and the target vehicle.

RENEX is a hybrid system which requires both conventional software and expert system software. The conventional software exists, so development involves only the expert system and an interface between the Symbolics and a Hewlett Packard 9000 which runs the Orbital Operations Simulator.

Initially the development team determined the generic functions of the system and proposed a system architecture. A prototype was built and demonstrated to human experts in rendezvous and proximity operations (called prox ops, the term refers to space vehicle maneuvers performed in close proximity to another vehicle). That was followed by a lengthy development of formal guidelines and requirements. Finally, a detailed system design of RENEX was produced.

3.15 Lockheed

AI Schedules Space Station Work

Lockheed Engineering and Management Services Co., Houston, has developed an expert system to provide on-board advice to space station operators when reconfiguring for unexpected, hazardous or resource-threatening events.

The expert system, called Space Station Expert System (SSES), works in conjunction with a simulation of the space station operator's command module written in FORTRAN and implemented on a Gould SEL 75. The expert system was developed with the ART expert system shell on a Lisp Machine Inc. Lambda 4 artificial intelligence workstation. It was described in a paper presented to ROBEXS '86 at Johnson Space Center.

The expert system is activated by a station operator who provides basic information on the problem or event. The information can include event type, expected duration, expected intensity and start time. The expert system then comes up with a plan and an exact timeline for all operator actions needed to prepare the station for the event.

Events can include meteor swarms, intense solar flares and on-board accidents.

When the expert system and the simulator are operated together on the ground, the expert system queries the space station simulator for

information on space station location and operating parameters, including the status of all subsystems. The reasoning component of SSES consists of 100 rules. The initial planning knowledge base contains 500 individual fact items.

When there is time prior to the event, all activities necessary can be detailed and performed to assure the space station is in a safe condition. When there is no time for extensive planning, decisions can be made by the system on omission of items, based on their pre-assigned priority value. Some of the checklist items can only be attempted at certain points in the orbit around the earth, and the expert system must "know" the position of the station and make allowance for those items.

The system was developed by Lockheed's Artificial Intelligence Computing Laboratory and Systems Engineering Department. In its current state of development, it is useful for evaluating the impact of expert systems technology on the hypothetical space station environment. However, a number of upgrades would have to be made before it could actually be used in space. Lockheed officials described four such improvements.

---First, the current SSES ZetaLISP utilities waste machine memory by using list duplication procedures rather than list surgery techniques. This degrades system performance.

---Second, the SSES reasoning component currently exercises a sequence of approximately 12 ART rules in the process of scheduling a single action request. This feature was originally helpful as a debugging aid, but is

inefficient in an operational mode. The collection of planning rules should be pruned to as small as possible to increase speed.

---Third, the depth of the current SSES knowledge base on any particular aspect of space station operation is shallow. A more realistic plan could be developed if a large number of alternative courses were available for each potential scenario.

---Finally, an enhancement could be made to allow SSES to actually implement all or part of the reconfiguration agenda on command from the space station operator. The feature would allow experimentation with semi-autonomous performance of expert systems. Now, a plan composed by SSES must be implemented manually by the operator, maintaining an "expert assistant" role for SSES.

3.16 MITRE

AI Schedules Space Shuttle Cargo

MITRE and Kennedy Space Center are jointly developing EMPRESS (Expert Mission Planning and Replanning Scheduling System) to determine the time, resources and tasks required to process payloads for the space shuttle.

It is being developed on a Symbolics 3600 LISP machine using the object-oriented programming language -- FLAVORS. EMPRESS is midway through its development phase, which continues through Fiscal Year 1987. The system

is expected to become operational once development is done. Each of the five modules of the system have been written, but are being changed to improve their performance or meet newly defined NASA requirements. They are:

---The scheduling module, which generates start and end times for each task required to prepared the payload.

---The resource module, which determines if a payload on a mission can be supported. If not, it recommends buying or building more resources or assigning their use more carefully.

---The constraint module, which monitors changes to some aspect of the plan or schedule to assure it does not violate constraints, such as milestone demands or precedence of tasks. It can infer constraints from the generic characteristics of the tasks.

---Scheduling heuristics (rules of thumb), which validate the schedule input by the user and resolve conflicts.

---The display module, which allows the user to display information with pop-up menus or use of a mouse.

3.17 MITRE

MITRE Expert System Monitors Rocket Fuel Loading

LES (Liquid Oxygen Expert System), by Carl I. Delaune and John R. Jamieson of Kennedy Space Center (KSC) and Ethan A. Scarl of MITRE, Bedford, Mass. monitors loading of oxygen into the space shuttle main tank. The purpose is to detect and diagnose failures in the hardware which controls fueling operations. The system isolates the failed component. It is important because the present Launch Processing System, a network of computers which control shuttle launch operations, lacks computational resources such as memory, speed and software techniques. In addition, KSC is losing launch personnel through retirement. Their expertise can now be captured through expert systems such as LES.

3.18 McDonnell Douglas

AI Automates Geosynchronous Missions

STALEX (Shuttle Trajectory and Launch Window Expert System) automates planning of space shuttle missions which carry geosynchronous communications satellites. It was developed by McDonnell Douglas Technical Services Co., Houston Astronautics Division. It performs launch window analysis and payload deployment scheduling. The goal of the system is to consistently choose the same solution as that of an experienced mission planner. A prototype was used for four space shuttle missions before flights were stopped due to the Challenger disaster. STALEX has reduced planning time by 70% over previous computer tools.

3.19 McDonnell Douglas

AI to Automate Shuttle Navigation

An Onboard Expert System (ONEX) under development will automate many of the navigational monitoring tasks aboard the space shuttle, particularly during nominal rendezvous.

The real-time prototype, being implemented in a mission control workstation at Johnson Space Center, Houston, is intended to help technicians design the most efficient software systems possible for the planned space station, and for upgrading the JSC mission control center.

The prototype was explained in a paper by M. A. Goodwin of the National Aeronautics and Space Administration and B. I. Talisman of McDonnell Douglas Astronautics Co. at the ROBEXS '86 conference at Johnson Space Center.

Officials of the JSC Mission Operations Directorate have helped evaluate and provide advice to the prototype's developers, and "have expressed interest in testing the product at the mission control center," said Goodwin and Talisman.

3.20 National Aeronautics and Space Administration

Several Expert Systems Under Development at JSC

The following systems are under development, or have been completed but are not operational, at Johnson Space Center, Houston, Tex., under direction of Robert H. Brown.

FDS Expert System

FDS is an expert system to aid in the use of the Flight Design System (FDS). The system will act as an intelligent front end to FDS to allow a user who is familiar with the capabilities of FDS to access the processors without detailed knowledge of the FDS executive. The expert system will have knowledge about what processors are required to generate a particular kind of information, how to link processors together, and how to build interface and sequence tables. The user of this system will provide a definition of the problem he would like to solve, and the expert system will prompt him for required inputs and construct all the information necessary to complete the mission design.

NAVEX: High Speed Ground Navigation Expert System Project

The high speed ground navigation task uses teams of three people on the console in the Mission Operations Control Center (MCC), during the ascent and entry portions of a shuttle flight. These people are responsible for monitoring and processing data from radar stations which are tracking the shuttle. This is a fairly typical MCC problem, requiring the operators to monitor a very large volume of data at a very high rate. This task requires

a fair amount of specialized human expertise: the operators typically take two years to train for the job.

The prototype expert system for this task, NAVEX, was developed by Inference Corp. in conjunction with JSC personnel in about three months. NAVEX was designed and built on a Symbolics computer (a specialized LISP machine) using ART, (Automated Reasoning Tool) a product developed by Inference Corp.

The NAVEX project demonstrated two key points; first, that current artificial intelligence technology was capable of handling typical JSC-type problems, both in complexity and speed, and second, the prototype system was developed in a very short time without relying on specialized "knowledge engineers."

MCC Workstation Expert System

The MCC workstation expert system program will provide position and velocity of the shuttle. The expert system will check to see if new TACAN data are available and build Lrbet 6 compatible data files, check to see if new IMU accelerometer data are available and determine if a maneuver has occurred, check to see if TDRSS, S-band, or C-band data are available and build Lrbet 6 compatible data files, and operate a Lrbet 6 filter program, keeping check on data quality which includes doing vector comparisons and restarting the filter when necessary.

EXEPS (Expert Electrical Power System)

The Expert Electrical Power System aids in scheduling spacecraft electrical power system activity blocks. Activity blocks are aggregates of electrical components. The Mission Planning and Analysis Division is responsible for characterizing the expected performance of the electrical power system before each flight, based on that flight's schedule of trajectory events and crew activities. This job requires expert knowledge of spacecraft electrical power systems. For the shuttle this task currently takes from four days to two weeks. EXEPS will function as an intelligent advisor, helping the user to obtain an activity block timeline that accurately reflects the known flight events and satisfies a set of predetermined constraints. The EXEPS project focuses largely on two areas of AI research, namely man-machine interface and planning technology.

MCC Software Status Expert System

This expert system monitors the Mission Control Center software status. Currently the job is done by the printer controller, a person who examines the on-line printer as it prints status and error messages and reports certain status information to various operations in the Control Center, primarily the computer supervisor. The expert system will recognize which of the status messages are important, what they mean, to whom they are important, and report the appropriate status information. It was designed and built with the expert system shell ART (Automated Reasoning Tool) from Inference Corp. in six weeks by a co-op student from Purdue University, Penny Clemmons, in 1985.

3.21 National Aeronautics and Space Administration

Research Institute for Advanced Computer Science Studies AI

The Research Institute for Advanced Computer Science is located at NASA Ames Research Center, Moffett Field, Calif. It is operated by the Universities Space Research Association, a consortium of 54 universities, under contract from NASA. It began operation June 1, 1983. Artificial intelligence plays a major role in the Center's work.

The ultimate goal of the RIACS research program is to integrate concurrent processing and artificial intelligence into a scientific tool that can automate scientific investigation. The Scientist's Aide is an expert system under study to assist in controlling experiments and collecting data, selecting specifications of computations of to solve a problem, writing the software needed to solve it and interpreting the results. The scientist will see pictures of the discipline, rather than the complicated programming languages now used. The pictorial method is called the method of cubes. For example, a NASA scientist would see and select a picture of an airfoil from his computer screen. He would stack it next to an airframe, as though he were building a picture of a space shuttle or other vehicle. The difference is that the picture he selected carries with the computational formulas to evaluate airflow around the airfoil. When he has finished building his space shuttle picture, he has also finished a mathematical model of the airflow around it.

RIACS is participating in joint projects to apply expert systems to aerospace problems. Four of the most important projects are: automatic grid generation being done for the Applied Computational Aerodynamics Branch, mission planning for the Infrared Telescope, automatic programming of space station systems for the Space Technology Branch and evaluation of aircraft configurations for the Aeronautical Systems Branch.

Expert systems for the space station will become a much bigger part of RIACS work as the space station effort increases.

3.22 National Aeronautics and Space Administration

Space Station Housekeeping Expert System Written

A space station expert system for housekeeping and maintenance on a 90-day mission, written in MuLISP for an IBM-PC, has been written by NASA aerospace engineers F.E. Mount and B.J. Woolford, both of Johnson Space Center, Houston. The system creates a recurrent priority-ranked housekeeping schedule for long term space missions. The program is a problem solving search system consisting of a data base, operators and controls.

3.23 National Aeronautics and Space Administration

Expert System Generates Rocket Fuel Loading System Schematics

LOX Expert System by Edwin New of Kennedy Space Center can produce schematics of the liquid oxygen loading system. The schematics generated can be used to understand the troubleshooting reports from another expert system called LES (previously described in this book). The program is written in LISP. LES can use LOX to automatically focus a user's attention on a particular spot of the liquid oxygen loading system, or it can be invoked manually with a mouse clicker. It sometimes is unable to fit all subsystem objects into the schematic window, but leftover portions can be put on a new page. Schematics drawings are generated directly from the knowledge base.

3.24 National Aeronautics and Space Administration

Expert System for Fuel Cell Developed at JSC

Ground controllers at Johnson Space Center, Houston, have developed a prototype expert system, using LISP, to automate fuel cell monitoring and determine if non-programmers can develop their own expert systems without knowledge engineers. The system, incorporating expertise of space shuttle flight control personnel, is intended to test automation of repetitive, monotonous jobs, said Marilyn K. Kimball and Larry A. Minter of NASA.

They used the Knowledge Engineering Environment (KEE) expert system shell by Intellicorp running on a Symbolics 3670 LISP machine for development.

The prototype "is an entirely data-driven, forward-chaining, real-time monitoring application," said Kimball and Minter. It contains 100 rules.

Chapter Four

Maintenance Expert Systems

4.1 Digital Equipment Corp

DEC Builds System to Write Tests

Digital Equipment Corp. has developed an expert system called Knowledge-Based Test Assistant that can generate test programs for digital devices at its Artificial Intelligence Technology Group in Hudson, Mass.

DEC official John E. Arnold gave a presentation on a component of that system, the Wave/Signal Editor (WSE), at the IEEE Second Conference on Artificial Intelligence Applications in Miami Beach.

The WSE can eventually be used for microprocessors as development on the expert system continues. These expert system will have seven modules when completed to perform various testing requirements. The WSE is implemented in VAX LISP. The relational data base used is VAX Rdb/VMS. At present, the Knowledge-Based Test Assistant runs on a VAX-11/785, under VMS with an attached VAXstation 100 high-resolution bit-mapped graphics terminal, but it is being converted to run on a Digital AI VAXstation.

The Test Assistant is used when a gate-level description is not available. When such descriptions are available, more conventional tools such as LASAR by Teradyne will still be used.

In order to write a test program, a meaningful description of the device's timing relationships is necessary, Arnold said. WSE gives the test engineer a means to produce such descriptions. Once available, the information can be used by other parts of the Test Assistant program. A knowledge engineering approach was used to develop the program. Test engineers explained how information in the specifications for the device, including text, charts and drawings, can be used to understand timing constraints for the device.

4.2 E-Systems

E-Systems Builds Flight Monitoring Expert System

The E-Systems Garland (Tex.) Division has developed a flight monitoring expert system called SECURE that can detect emergencies, generate a solution for the crew, and "know" if the crew is aware of the problem.

Work on the first two tasks has been completed, and E-Systems is at work on the subsystem that will determine, from crew actions, whether the crew is aware of the problem, E-Systems official David C. Chen told the IEEE Second Conference on Artificial Intelligence Applications in Miami Beach.

Currently the more advanced SECURE system runs in FranzLISP on a VAX 11/780, and can generate flight control movements for a simulated aircraft to guide it between any pair of six airports. It can recover from such emergencies as: a weathered-in destination airport, tail wind and head wind components which alter the time of flight and fuel required, engine failure, thunderstorm in the flight path and stuck flaps.

An older version of SECURE called a script-based SECURE flight monitor, because it contains scripts of flight conditions and emergencies in its memory, is implemented for the McDonnell Douglas DC-10 aircraft simulator, running on a PDP-10 computer. The flight monitor is written in MACLISP. It contains scripts of procedures to use for normal flight, as well as single-engine-failure climb, and single and dual engine failure landings.

The problem with the earlier, scripted flight monitoring computer occurs when the system sees unusual emergencies for which it does not have a script. The situation can be corrected somewhat by simply building a bigger script into memory. That only gives the crew a bigger list of known emergencies, however, and the purpose of a computerized flight monitor is to detect the unanticipated.

An example of how it works can be seen from the way it handles a thunderstorm emergency. The system's trajectory planner tells the route planner that the present flight path is unacceptable. The route planner plans a different route, but first makes sure there is enough fuel.

4.3 General Electric

Expert System Troubleshoots the F-15 Fighter

Aircraft and computer specialists worked together to build a prototype expert system to help maintenance technicians diagnose problems in the F-15 Eagle fighter that has saved time and reduced numbers of personnel required.

Building the expert system required the skills of a knowledge engineer and technicians who know about maintenance on the F-15.

It covers 15 of the 167 default codes found in malfunctions of the F-15 flight control system. The knowledge base for the 15 fault codes in the expert diagnostic system is covered in 44 rule tables, involving 621 facts and 223 rules.

Use and development of the system was described by J. Davidson and M.J. Zampi in a paper they delivered at the National Aerospace and Electronics Conference in Dayton in 1986.

Davidson works for the Air Force Flight Dynamics Lab Control Division, while Campi works for General Electric Co. Aerospace Control Systems Dept.

The system is designed for use in a flight line shack at F-15 air bases, and can head off two problems that increasingly plague the maintenance of sophisticated aircraft: rising complexity of the systems and decreasing numbers of skilled technicians.

4.4 Rockwell Autonetics Strategic Systems Division

B-1 Bomber to Use Artificial Intelligence for Repairs

The second phase of a ground-based maintenance expert system for the Rockwell B-1 bomber is ready to begin and includes development of a prototype that will be tested at Dyess Air Force Base for five months.

The expert system was described in a paper by Kathy Davis of Rockwell Autonetics Strategic Systems Division, Anaheim, Calif. before the National Aeronautics and Electronics Conference in Dayton, Ohio.

The evaluation will determine whether maintenance personnel accept the expert system into routine use. It will also be a test of running an expert system in a multi-user workstation environment. It will be connected with the Air Force Management Information System which is still evolving. If successful, the project will proceed to the third and final phase which will see use of the system at all B-1B main operating bases.

The system is called CEPS (Central integrated test system Expert Parameter System). The first phase demonstrated isolation of fault

ambiguities and reduction of the number of retest okays. The Central Integrated Test System (CITS) is the base for the expert system. It performs in-flight monitoring and reads parameters every 30 minutes: readings are taken more often if a fault is detected. Once the CITS data gets back to the ground, it is analyzed by CEPS. There is a shortage of personnel to analyze all the data returned manually, and CEPS can aid in reduction of the personnel needed.

CEPS performs its failure isolation via a combination of expert system and more conventional computer techniques. The conventional techniques are used for report generation. The phase one demonstration was performed on three Symbolics 3640s that were networked to a DEC VAX 11/785. The B-1 subsystems studied during the first phase are: electrical systems, environmental control systems, flaps and slats, and stability augmentation system.

4.5 Honeywell

AI System Checks Torpedo Tests

FLEET/DRAS (Data Reduction Analysis System), an expert system to aid Navy technicians in quick-look analysis of torpedo sea trials, has been developed by Honeywell Systems and Research Center and Honeywell Undersea Systems Div.

A paper on the system was presented at the IEEE Second Conference on Artificial Intelligence Applications in Miami Beach in 1985.

A sea trial generates about 50 Mb of data, and many sea trials are required for development. In addition, anomaly detection, which has been performed by an expert engineering analyst, will be automated. A prototype expert system for that has been developed at Honeywell, and follows the rules of a human analyst. In tests, it detected all the anomalies it was designed to find, and found two that had previously gone unnoticed by the human experts.

The quick-look process requires three steps: anomaly detection (automatic), evaluation of selected data (done by a technician) and diagnosis of a probable cause (done with an expert system not yet developed to act as diagnostic aid to the technician).

Using the new system, the quick-look analysis can be done in hours rather than days. The expert system for anomaly detection has 70 rules, but it will be followed by a more comprehensive system that can find faults in sonar and propulsion systems. The prototype system has been exhaustively tested against actual sea-run data which contained known anomalies. Some of the rules of thumb used in the prototype were abstracted from those same runs.

The prototype was developed in the FLECS/FORTRAN system, since the existing non-automated data reduction system was written in FORTRAN.

Honeywell researchers found an expert system development tool called AGE/INTERLISP was too slow.

4.6 RCA

Expert System Eases AEGIS Repair

Testing of artificial intelligence software that mimics the actions of an expert radar repairman have been conducted aboard a Navy AEGIS-class guided missile cruiser, RCA scientists said.

The AEGIS Combat System Maintenance Advisor, an expert system, incorporates 2,000 rules used by human repairmen to keep the SPY-1A phased array radar operating. It is the heart of the AEGIS combat system, but is one of the most complex military electronic systems in existence.

The expert system advises less-experienced repair crews on finding the cause of malfunctions. It is termed a success by its developers at the RCA Artificial Intelligence Laboratory, Moorestown, N.J. They are: George Drastal, Tom DuBois, Lori McAndrews, Stan Raatz and Nick Straguzzi.

The software program obtains information about the problem through a question and answer dialogue with Navy personnel. It can:

---Request Navy personnel to make tests, using built-in test equipment in the SPY-1A,

---Use information available to operators on display screens, after the information is typed into the expert system,

---Pick out false errors caused by mistakes in setting up the radar equipment or operating it, and errors resulting from environmental conditions,

---Suggest temporary repairs to avoid shutting down the radar,

---Determine the impact of the radar system failures on combat readiness.

4.7 Vitro

Expert System Tests Cruise Missile

An expert system to isolate faults in ground-launched cruise missiles has been developed in-house by Vitro Corp., Silver Spring, Md.

The GFIX system (Ground launched cruise missile Fault Isolation Expert), still in prototype stage, is designed to run on a portable laptop microcomputer such as the Grid Systems GridCase, and uses a backward chaining inference engine to check out pre-launch cruise missiles, isolate problems and recommend repair, and then retest the missile's control system following repair.

Dave Hillman, knowledge engineer at Vitro's headquarters, said the GFIX system was recently demonstrated to Air Force engineers at Wright-Patterson Air Force Base, Dayton, Ohio. "The concept behind GFIX is to make it extremely easy to operate, and not just for the computer literate."

Air Force officials are reportedly interested in the product because it provides a steady reliable method of quality control in an important maintenance phase of a weapon system which depends on precision guidance to function properly.

Hillman said an expert system like GFIX conceivably could replace bulky text manuals on electronic components and eliminate the need to train maintenance personnel individually to operate complicated electronics systems. The engineer said Vitro is currently looking at expanding the use of the expert system's inference engine to other military and commercial applications as well.

Hillman said the development of GFIX is unique in that it is the product of systems engineers who also possess working knowledge of weapon systems development and their guidance processes. It was they who designed a "practical" expert application.

"GFIX is fundamentally goal directed. It asks the system to prove it is operational by methodically testing step by step each part until a fault is isolated and tested down to the lowest replaceable unit," said Hillman.

GFIX currently contains 400 data points and 250 rules, and resides on a Grid laptop with 640K of RAM.

Chapter Five

Expert System Building Tools

5.1 Timing the Expert System Shells

NASA Finds Out Who is Fastest

The Artificial Intelligence Section at Johnson Space Center, Houston, has completed timing tests of several expert system building tools, also known as "shells," running on a variety of computers.

The benchmark used for testing was a sample problem well known in the artificial intelligence industry: the monkey and bananas problem. The problem requires subgoals to be generated and accomplished by an expert system written with one of the tools. For example, the monkey must be holding the bananas to eat them and that becomes a goal. The problem requires 30 rules.

One of the companies, Intellicorp, performed the test themselves and got runtimes that were shorter than those reported by Johnson Space Center officials. The comparisons also provided a test of artificial intelligence computers as well as expert system shell software.

Computers tested were: Symbolics 3640 with 4MB of memory, LMI with 2MB of memory, Texas Instruments Explorer with 4MB of memory, VAX 11/780, Hewlett Packard 9000, IBM PC with one-half megabyte of memory, IBM AT with one-half megabyte of memory, Apple MacIntosh with one-half megabyte of memory, Sun 3/75 with 4MB of memory and a Hewlett Packard 320 workstation with 6MB of memory.

Expert system building tools tested were: ART by Inference, CLIPS by the Johnson Space Center Artificial Intelligence Section, OPS5 by Charles L. Forgy, OPS5 by DEC, OPS5+ by Artelligence, ExperOPS5 by ExperTelligence and KEE by IntelliCorp.

The test results were reported in a memo by Gary D. Riley of the Johnson Space Center Artificial Intelligence Section. He warned readers not to draw far-reaching conclusions from the speed tests. "This benchmark is just one of many possible benchmarks and does not fully test the capabilities of the expert system tools. For example, to draw the conclusion that ART is a better expert system tool than KEE or that KEE is a better expert system tool than ART is beyond the scope of this study," Riley wrote.

The results show that ART 2.0 running the test program on a Symbolics machine had the fastest time of 1.2 seconds. Two others were close behind: the DEC OPS5 2.0 running on a DEC VAX took 1.3 seconds, while OPS5 by Forgy, running on a Symbolics, took 1.7 seconds.

Next came a group of three software-hardware combinations requiring about three seconds. ART running on a Texas Instruments Explorer took 2.4 seconds, while ART running on an LMI and CLIPS running on a Sun both took three seconds.

The next three test results were clustered at five seconds. CLIPS running on both the DEC VAX and the Hewlett Packard workstation took five seconds, while OPS5+ running on an IBM AT took 5.2 seconds.

Next fastest was a benchmark test of ART, performed by Inference, running on a Symbolics, which took 7.6 seconds. CLIPS running on the Hewlett Packard 9000 took 13 seconds, while OPS5+ on a MacIntosh took 14 seconds.

After that, the times began to increase dramatically. ART version Beta 3, running on a VAX, took 17 seconds while KEE version 2.1, tested by IntelliCorp on a Symbolics, took 17.8 seconds. Both OPS5+ on an IBM PC and CLIPS on an IBM AT took 19 seconds.

ExperOPS5 version 1.04 took 55 seconds to run the monkey and bananas problem on a Macintosh while CLIPS on an IBM PC took 57 seconds.

Finally, KEE version 2.1 took 165 seconds to run the problem on a Symbolics.

Memory size had little effect on test results since the problem was small.

5.2 W. W. Gaertner Research

A "Supercharger" for Expert Systems

W.W. Gaertner Research, Norwalk, Conn., has developed an artificial intelligence "supercharger" that speeds execution of expert systems 1,000 to one million times and costs $100,000.

Wolfgang W. Gaertner, president, is developing the computer speed-up device, which he calls (AI)*2, under a $68,000 Small Business Innovation Research contract from the Air Force and a $400,000 contract from the Army.

The contract from the Aeronautical Systems Division at Wright-Patterson Air Force Base, Dayton, Ohio, calls for the device to speed a pilot's aid expert system in an aircraft. Gaertner said the size of the device will be 7x10x19 inches. He also said the present cost of $100,000 will not provide a device that meets military specifications, and might cost more for military purposes. The Army Signal Warfare Laboratory is interested in the device to speed operation of an expert system that could perform as a human signal jammer expert would. The device could be deployed behind enemy lines in an artillery shell, drone aircraft or left behind by departing troops.

The device will accelerate frequently used expert systems. The more specific the purpose of the expert system, the greater speed increase that can be realized. The speed-up is achieved by making high-level operations

run faster through use of parallel processing. Gaertner said he developed the parallel machine. He said, in a telephone interview (phone: 203-866-3200) that the device uses a language that is somewhat similar to C. It will connect through an ethernet port to machines running artificial intelligence software, including Symbolics and DEC VAX.

The Air Force six-month contract is nearly over, but work will continue through the Army contract. He estimated it will take six months to a year to develop the "Robot Jammer" expert system. Meanwhile, Gaertner hopes the Air Force contract will result in a follow-on phase two award. He does not have a specific pilot-aid expert system in mind, but said the supercharger could be useful in the Pilot's Associate Program recently awarded to McDonnell Douglas and Lockheed by the Air Force and the Defense Advanced Research Projects Agency. Gaertner is also considering similar technology for a rapid data base processor under a Rome Air Development Center contract.

The concept involves a modular system consisting of two major components: a high-performance processor, capable of executing artificial intelligence software in non-real time, and an "artificial instinct module" with a superfast search and post-processing mechanism for prestored responses which are retrieved and implemented in real time.

Working in conjunction, the intelligence module updates the instinct module during breaks in the action. The proposed new system will use statistical analysis to resolve incomplete and contradictory sensor data.

5.3 A Review of the Better Known Shells

NASA Aims a Critical Eye at Expert System Tools

The Artificial Intelligence Section of Johnson Space Center, Houston, has completed a memo detailing 16 expert system building tools, software programs that are used to build expert systems.

The author has called most of the firms who manufacture the shells to update information: thus, part of the information below is from the NASA memo by Chris J. Culbert and part is from telephone interviews. While slightly incomplete, this listing is useful for those new to machine intelligence technology.

---Automated Reasoning Tool (ART) by Inference Corp., 5300 W. Century Blvd., Los Angeles, Calif. 90045. ART has full forward and backward chaining with a powerful pattern matching syntax. NASA has a great deal of experience with ART, which is a primary research tool for expert systems. ART has hypothetical reasoning and uses the schema system for object description. All ART features are integrated. ART is also integrated with LISP. An ART expert system may be embedded within a larger system on the Symbolics computer. ART uses multiple windows and a mouse interface. There are no knowledge acquisition aids or uncertainty management. The base language is LISP. ART is available on LISP computers (Symbolics, LMI, Texas Instruments Explorer, Xerox, etc.).

---Knowledge Engineering Environment (KEE) by Intellicorp, 124 University Ave., Palo Alto, Calif. 94301. KEE has forward and backward chaining rules, but does not have hypothetical reasoning. Like ART, KEE is one of the most prominent expert system research tools in the machine intelligence field. KEE provides full object description, based on frames. All features are integrated. KEE is integrated with LISP. A system developed in KEE may be embedded in a larger system. Like ART, KEE uses multiple windows, menus and a mouse. There are no knowledge acquisition aids, and no explicit uncertainty management. It is available on LISP machines.

---Knowledge Craft by Carnegie Group, 650 Commerce Court, Station Square, Pittsburgh, Penn. 15219. Knowledge Craft provides OPS5 for forward chaining, and PROLOG for backward chaining. It does allow reasoning about alternate problem solutions. It has full object-oriented programming capability. NASA officials were told in June, 1985, that Knowledge Craft does not have feature integration, but Carnegie Group officials said that has been improved. It is integrated with LISP. Knowledge Craft provides multi-windows, a mouse and graphical interface on LISP machines. There are no knowledge acquisition aids and there is no uncertainty management. The language is Common LISP. It is available on LISP machines, DEC VAX machines and PERQ computers.

---S.1 by Teknowledge, 525 University Ave., Palo Alto, Calif. 94301. There is backward chaining, but no forward chaining and no hypothetical reasoning. S.1 has full object description with a frame based system. Features are fully integrated. S.1 is integrated with LISP, while C

versions allow access to C. Systems developed in S.1 can be embedded. The development environment includes intelligent editors, interactive graphical windows and full tracing and debugging. Uncertainty management is provided through confidence ratings. The base language is LISP, C and possibly Ada. NASA said an Ada version has been announced, but the company would not discuss such a version. It can run on LISP machines, DEC VAX, Apollo, Sun, NCR Tower and IBM RT computers.

---Expert System Environment (ESE) by IBM, P.O. Box 152560, Irving, Texas 75015-2560. IBM was unable to provide information but NASA talked with one of the ESE developers. ESE has forward and backward chaining based on the EMYCIN model. There is no hypothetical reasoning. Object description provides only parameters and values. Features are well integrated. It is integrated with any language that runs under the VMS operating system. Systems can be embedded. It has intelligent editors for rule and object editing that catch syntactic and semantic errors. There are no knowledge acquisition aids. It has uncertainty management based on the MYCIN model. The base language is PASCAL. It is available on the IBM 370 under the VM/CMS operating system.

---The Intelligent Machine Model (TIMM) by General Research Corp., McLean, Va., 703-893-5900. It has forward chaining, but no backward chaining or hypothetical reasoning. Object description is in terms of the attributes of a single problem. The TIMM features are integrated. TIMM allows access to external files and data through the REASON program. NASA said TIMM can not be embedded, but General Research said that has been improved. The primary user interface is through prompts to the user. TIMM

has knowledge acquisition aids and tells the user when additional examples are needed. TIMM has uncertainty management. The base language is FORTRAN 77, and it runs on the IBM XT/AT, compatibles and mainframes that run FORTRAN 77.

---Rulemaster by Radian Corp, 8501 Mo-Pac Blvd., P.O. Box 9948, Austin, Texas 78766. Researchers say Rulemaster is a simplified form of machine intelligence and is therefore not "true" artificial intelligence. There is no forward chaining, but there is backward chaining through decision tree induction. There is no hypothetical reasoning, but Radian officials say they do have object description. As for feature integration, the decision tree facility is the only problem solver offered. It can access any language that runs under UNIX. The ability to embed programs written in Rulemaster has been improved in release 3.0. Rulemaster builds a decision tree from examples provided by the user. It has uncertainty management through Zadeh's fuzzy logic. The base language is C, and it runs on the DEC VAX, Sun, and IBM PC/XT.

---Knowledge Engineering System (KES) by Software Architecture and Engineering, 1500 Wilson Blvd., Suite 800, Arlington, Va. 22209. It has backward chaining but no forward chaining. It has hypothetical reasoning. Release 2.2 will provide true, independent object descriptions. Features of KES can be integrated through the operating system. It is sold in pieces, and generally used by experts. There is language integration. KES authors spent $5,000 adding capability to the system to allow it to be embedded. The development environment is a standard programming interface, but that does not include an editor or graphical windows. KES has uncertainty

management. The base language is LISP and C. It is available on DEC VAX, CYBER and Apollo workstations, and the IBM PC.

---Personal Consultant by Texas Instruments, P.O. Box 809063, Dallas, Texas 75380. It has limited forward chaining and full backward chaining, both being based on EMYCIN. There is no hypothetical reasoning, but there is object description through a frame-like system called Contexts. All features are integrated and there is language integration. Personal Consultant runs stand alone, but can be called from an IQ LISP program. It has windows, editors and debugging tools. There are menu and dialogue-oriented knowledge acquisition aids. It has EMYCIN uncertainty factors, and the base language is IQ LISP. It is available on IBM PC and Texas Instruments computers.

---Personal Consultant Plus by Texas Instruments, P.O. Box 2909, MS 2244, Austin, Texas 78769. It has full forward and backward chaining, but no hypothetical reasoning. It has object description and feature integration. It also has language integration, allowing functions to be called from forward or backward chaining rules. It cannot be embedded. It uses windows, intelligent editors and debugging tools. It uses standard EMYCIN uncertainty factors. The base language is Scheme, a LISP dialect. It runs on IBM PC and Texas Instruments computers.

---OPS5, developed at Carnegie-Mellon University and now appearing in numerous versions. It has full forward chaining but no backward chaining or hypothetical reasoning. It has limited object description and good feature integration. Language integration is limited to the ability to call

functions from the right hand side of the rule. Passing of data to an external language depends on the implementation, and can be very clumsy. The development environment for the DEC VAX is simple and unsophisticated. There are no knowledge acquisition aids or uncertainty management. The base languages are usually BLISS, MACLISP or FRANZ LISP. It is most commonly found running on a DEC VAX, but can run on a Symbolics.

---OPS5+ by Computer Thought Corp. 1721 W. Plano Parkway, Room 125, Plano, Texas 75075. Computer Thought recently won this product back from Artelligence through court action, charging it was built by Computer Thought employees before they joined Artelligence. OPS5+ has forward chaining, but no backward chaining or hypothetical reasoning. Limited object description is available, as is feature integration. Language integration allows users to call C functions from the right hand side of a rule. It may be embedded. It provides windows and a mouse. There are no knowledge acquisition aids or uncertainty management. The base language is C. It runs on an IBM PC/XT/AT, the Macintosh and the Sun.

---Expert Ease by Expert Software International, c/o Jeffrey Perrone and Assoc., 3685 17th St., San Francisco, Calif. It has no: forward chaining, backward chaining, hypothetical reasoning, object description, feature integration, language integration or embedding capability. The reason for that, an official of the company said, is that Expert Ease is intended to be a stand alone package that is extremely simple to learn and use. It also could not solve the NASA benchmark problem. It provides a spreadsheet style format for users to define problems. It is a simple

decision tree builder, and has no uncertainty management. The base language is PASCAL. It runs on IBM PC and compatible computers.

---M.1 by Teknowledge, 525 University Ave., Palo Alto, Calif. 94301. It has no true forward chaining, although it can be done, but does provide full backward chaining. There is no hypothetical reasoning. There is no object description. Language integration can be done through C, but systems built with M.1 cannot be embedded. There is full certainty management. The base language is C. It is available on IBM PC and compatibles. It was originally intended as a rapid prototyping tool, but is becoming more stand alone for small expert systems.

---OPS83 by Production System Technologies, 642 Gettysburg St., Pittsburgh, Penn. 15206. There is full forward chaining, while backward chaining can be implemented. There is limited object description and full feature integration. Rules are tightly coupled with external rules. Systems can be embedded. There are no knowledge aids or uncertainty management capabilities. It is a procedural language that can use OPS5 type rules. It combines a PASCAL like syntax with OPS5 type rules. It runs on DEC VAX, Sun, HP 9000, MS-DOS machines like the IBM PC/XT/AT and clones.

---Lockheed Expert System (LES), a shell that is proprietary to Lockheed. It can use forward chaining rules and provides full backward chaining, but has no hypothetical reasoning. It has full object description and feature integration. It can call external functions written in Ada, PASCAL, FORTRAN or PL/1. LES cannot be embedded. It provides extensive tools for debugging and executing an expert system. There are no knowledge

acquisition aids, but there is uncertainty management. The base language is PL.1 and Ada. It runs on DEC VAX computers.

5.4 A Closer Look at ART

ART Wins NASA Confidence

ART, a software tool by Inference Corp. used to build expert systems, has been termed a powerful program that is difficult to learn to use well and suffers from too much copy protection in a memo by the National Aeronautics and Space Administration.

Evaluation of the Automated Reasoning Tool has been completed by Chris J. Culbert of the Artificial Intelligence Section of the National Aeronautics and Space Administration's Johnson Space Center, Houston.

ART has been used by the AI section to create several expert systems. ART is also called an expert system shell, because it is the framework in which an expert system is built. Systems built by NASA in Houston using ART are:

---NAVEX, to aid flight controllers on the high speed navigation console in the mission operations control room for real-time process monitoring and control;

---MCCSSES, to aid flight controllers who monitor the hardware and software status in the mission control center for real-time data monitoring and fault diagnosis;

---ESFAS, to aid users of the Flight Analysis System, which designs shuttle missions, for an intelligent front end to a complex software design system;

---EXEPS, to aid engineers who analyze space shuttle electrical power and crew consumable requirements, for planning and scheduling of electrical power loads.

Overall, ART was described as a strong tool for developing expert systems. It is the only tool available for systems which require hypothetical reasoning, although speed may be a concern, the NASA memo states.

Strengths of ART, as evaluated by Culbert in a February memo, include speed. ART executes 90 rules per second, which is faster than most expert system building tools. The language is powerful, with syntax and structure that are stronger than the poplar OPS5. The integration of LISP, the computer language most commonly used in the U.S. for artificial intelligence research, is well handled. There is complete integration of the object data base and the fact data base. One of ART's strongest features is the viewpoint mechanism, which allows simultaneous reasoning along multiple paths. Window and menu interface commands are useful. A

feature called the ART Studio allows debugging of ART applications, and a spelling checker guards against incorrect entries.

Weaknesses of ART include schemata which, while useful for describing objects and relationships, does not provide full object-oriented programming because they do not provide for direct message passing between objects. Information stored in schemata is not accessible from LISP. Use of schemata for storage of icon information by the program's ARTIST system quickly leads to an explosion in the size of the data base. The problem makes ARTIST unsuitable for animated graphics. While it is not difficult to learn to use ART, or build simple rule-based systems, it is difficult to learn to use ART well. ART documentation is generally acceptable, but the reference manual does a poor job of showing how to use features of ART because it does not have enough examples.

"Finally," Culbert said in the memo, "ART is a heavily copy protected product. A machine dependent key is required to execute the program,and the code is totally encrypted. All internal functions have a randomly generated name. This makes the code nearly impossible to break, but also handicaps the user when attempting to debug systems."

NASA is now developing its own expert system shell, which will provide a tailor-made system with source code that is available to NASA.

Johnson Space Center's technology development office is building an expert system shell in C so that expert systems constructed with it can be moved easily among various types of computers. The issue of validation is

a serious one to NASA. Only advisory expert systems will fly in space until those which control critical parts of a mission can be tested thoroughly.

5.5 A Closer Look at KEE

KEE Wins NASA Respect

The National Aeronautics and Space Administration has found that an expert system building tool called KEE (Knowledge Engineering Environment) has a number of strong features but lacks a good rule system.

An evaluation of KEE, among the best known expert system building tools in the artificial intelligence research community, has been completed by NASA.

KEE, by IntelliCorp, was evaluated by Chris J. Culbert of the Artificial Intelligence Section at NASA's Johnson Space Center, Houston. NASA researchers built two expert systems with KEE to evaluate the expert system tool: ESFAS, an expert system used in flight analysis, and an expert system to analyze space station resource requirements and usage. The evaluation was made on KEE version 2.0.

NASA found KEE has a number of strong features, such as the object-oriented design approach for modeling complex systems, and their relationships, in a natural fashion. Using the interactive, visual

interface, Culbert said in a memo to Johnson Space Center officials, a knowledge representation can be built and tested rapidly. The major weakness of KEE is the rule system, NASA found, whose, "...poor performance and limited syntax may make KEE difficult to use for real-time process-control problems. (An IntelliCorp official said version 3.0 of KEE, now being tested, incorporates numerous changes to the rule system.)

Strengths include ease of use and the speed with which a prototype expert system can be built. Knowledge representation is graphed for the user in multiple tree--like structures. KEE methods provide message-passing capability. The methods are written in LISP, but have access to all of the KEE data bases. Active images are another strong feature. They provide a large number of icons and windows for displaying or changing the status of the system parameters. Users can easily build custom interfaces to their own expert systems, which is, "...no small feat on the complicated Symbolics (AI computer)," Culbert wrote. KEE is easily extendable and allows for customized use. It has an open architecture.

Weaknesses of KEE include the rule system. While it is a drawback, it does not prevent reasoning. IntelliCorp believes it far more appropriate, Culbert said, to store most factual information in objects, as opposed to a fact data base or rules. Therefore, KEE expert systems require fewer rules than in a typical production system. However, although the tendency is to use active values and methods to accomplish reasoning, Culbert said this is not always the best way to solve a problem. There are times when a rule is the best way to describe a problem solution. Although KEE's rule system

allows forward and backward chaining, it is very weak. The pattern language is restricted to the tell and ask format.

NASA found expert systems created with KEE to be slow in execution when using rules to reason. KEE provides its own editor for working on objects and rules. However, it is not a full ZMACS editor and did not support many of the ZMACS capabilities, such as keyboard macros. Although this is not entirely necessary, Culbert said, it would be preferable to have a full-bodied ZMACS editor for editing data structures.

KEE does not have a hypothetical reasoning capability, but Culbert said in a memo that the feature will be added in a future version KEE.

In general, the KEE rule system was more difficult to access and use than in a rule-based production system. Despite this, there are some nice features to the rule system. For example, Culbert said, users can define their own conflict resolution strategy for forward chaining. Also, the backward chaining trace and explanation facilities provide a large amount of information about the reasoning process. The tell-and-ask format which was awkward for rule firing from within a running system was good for querying the data base, NASA officials found.

Chapter Six

Expert Systems For Manufacturing

6.1 Boeing

Boeing Puts AI on the Shop Floor

A 1,000-rule prototype expert system aids Boeing Electronics Co. shop floor personnel in the assembly of electrical connectors and has demonstrated 100% accuracy, Boeing Artificial Intelligence (AI) Center officials W. J. McClay and P. J. MacVicar-Whelan told an AI gathering in Orlando.

A production prototype is being developed to replace the partial scale prototype system now used on a trial basis. The system "memorizes" 20,000 pages of documents containing specifications for 150 connector types. The system can tell a worker which of some 200 tools to use and provide information on techniques and materials involved.

Boeing officials first explored the possibility of a cheap system using commercially available expert system shells running on an IBM PC. That effort proved to be grossly optimistic. Finally, Boeing chose the PROLOG

language running on a Vax 11/780 with the VMS operating system. The full scale production version will be ported to a MicroVAX 2 with a dozen terminals, and will use QUINTUS PROLOG. Boeing officials intend to use technology developed for assembly of connectors in other areas of manufacturing.

The system was described to an artificial intelligence meeting in Orlando, Fla. sponsored by the Society of Photo-Optical Instrumentation Engineers.

Tests of connector assemblies with the partial-scale expert system have found no errors. Time to research the proper assembly process has been reduced from 42 minutes to 10 minutes. Both old and new employees are pleased with the clarity and uniformity of the system's guidance. A drawing change notice was incorporated in the system in less than five minutes.

6.2 Creative Enterprises

Expert Systems Design Space Power Systems

Creative Enterprises, San Diego, Calif., designs complex space power systems -- both nuclear and non-nuclear -- with a newly developed smart design system.

NOVICE, originally developed under a Fiscal Year 1984 Small Business Innovation Research contract, was described to an Albuquerque, N.M.,

conference on space nuclear power systems for spacecraft. "Up to now, there has been a thrust toward using expert systems for spacecraft power management," Creative Enterprise official Ralph S. Cooper said. "We decided to tailor a system to space nuclear power design," he said, adding that he prefers to call NOVICE an "advisory" rather than an "expert" system.

The product comes to market at a time when NASA, which oversees the Small Business contract, is looking closely at nuclear reactors for a "growth space station." Such reactors could force a redesign of the space station, depending on whether the reactor is loosely tethered to the station, mounted on a boom or operated as a free-flyer. Other issues include how it will be refueled, maintained and discarded at the end of its service life.

Meanwhile, the Strategic Defense Initiative (SDI) program is mapping out a major program in multimegawatt nuclear and non-nuclear space power to add to its current SP-100 nuclear reactor program. Designs under discussion for the multimegawatt program include burst powers up to 1000 MW or beyond. These must be reached within five seconds from a "housekeeping" power rating of perhaps 0.5 MW. SDI specialists indicate that the space-based multimegawatt program, combined with an existing SDI emphasis on pulse power and energy storage technologies, will impose complex problems of power distribution without spacecraft shorting, spacecraft integration and self-generated plasmas.

Four existing expert tools were evaluated for the 100-rule NOVICE: Carnegie-Mellon University's OPS5, the Teknowledge S.1, Inference Corp.'s

ART and Intellecorp's KEE. The firm sought to build a "deep model" that could combine program architectures, including modular or "surface" expert systems and algorithms, with domain information to handle complex space nuclear power design problems. However, the first three tools turned out to be inadequate, since they achieved all control through traditional production rules. Many of these reflect applications where rules can be fired independently without much consideration for ordering. Space nuclear power designs require sequential and dependent activation.

Only KEE (Knowledge Engineering Environment) could break out of the production-rule paradigm. It provided "true frame representations of knowledge, including inheritance, very sophisticated graphics capabilities, and a complete rule evaluation environment."

NOVICE is designed to tackle the immense variations in mission requirements, load profiles, power levels, durations and environments common to space nuclear power systems -- especially when requirements and technology are ill-defined. Despite such factors, mission and spacecraft planners must evaluate a variety of concepts before selecting one for development. One collateral benefit of NOVICE is a large validated database containing the current and projected component performance and cost.

The firm first evaluated solar photovoltaic, solar dynamic and nuclear reactor designs through interviews with 50 user organizations. The NOVICE data base covers reactor sizes and weights, turbines, electric generators, working fluids, heat rejection systems, fuel characteristics and lifetime and power limits. Rules include weight- and size-scaling laws, subsystem

interactions and compatibility, and evaluation criteria. A third element -- user requirements -- covers mission duration and power, weight and cost constraints, performance criteria, and mission initial operational capability.

The resultant NOVICE output is a range of conceptual designs that include power sources, converters, heat rejection and other major structural elements like shielding, along with design and operating parameters, selection rationales and documentation, and anticipated performance.

It can handle nine power types -- primary batteries, solar photovoltaic, chemical dynamic, radioisotope thermoelectric generators, primary fuel cells, nuclear with static converters, nuclear with dynamic closed and open cycles, and solar with dynamic converters. A wide range of subsystem options exist for each type in shielding, heat transport, radiator design, power management, and structure. "Many other factors must be considered as well -- average and peak power, trajectory and orbit, manned vs. unmanned status, safety, reliability and maintenance," he added. These more specialized factors may be incorporated in a proposed successor named SPEED (space power expert evaluation and design).

In operation, the NOVICE program asks the user for inputs on mission power and duration, trajectory and manned status. The code returns with a list of acceptable space nuclear power types sorted by mass for any mission.

6.3 Digital Equipment Corp.

PEARL Helps Lay Out Power Supplies

Digital Equipment Corp. has created an expert system called PEARL (Power supply Expert Assisted Rule-based Layout) that provides assistance to printed wiring board layout designers, DEC scientists Edward J. DeJesus and James P. Callan told a IEEE artificial intelligence conference.

DEC released the system for use as a tool in the company in 1985. The system will be enhanced during its first year in the field. Work has begun to add printed wire routing advice to the system. Eventually the system will be equipped with dynamic checking and signal integrity knowledge. Currently a designer uses physical layout tools, and then uses analysis tools to determine whether the board will function properly.

The programming languages for the system are BLISS and OPS5. Before PEARL, power supply designs at DEC were laid out manually or on computer aided design systems which had no logic information, automatic tools or analysis capabilities. Layout designers manually placed and routed prototype boards which were then built and tested to see if they worked, DeJesus and Callan said. The average power supply is laid out several times before the right design is found.

PEARL's knowledge base consists of constraints and critical layout information, specific to power-supply designs. The knowledge is captured

from human engineers using a fill-in-the-blank screen. Previous to PEARL such information was passed verbally or marked on a schematic.

The system can be used in three modes: manually, semi-automatic and automatic. The semi-automatic mode is the default mode. All three modes use the same keypad, which contains such commands as select, unselect, move, rotate, explain, help and window.

6.4 Los Alamos National Laboratory

Los Alamos Building an AI Weapon Designer

Los Alamos National Laboratory is at work on two expert systems that can design nuclear weapons: one makes the design process easier to use, and the other designs the weapon after receiving a description of it from an engineer.

The two systems are called Procon and Designer's Apprentice. Design of nuclear weapons is currently done with large FORTRAN simulation codes which are run on Cray supercomputers.

Procon is an expert system that provides an interface between users and several simulation codes. It knows what inputs are required for the weapons codes, what ranges and forms those parameters have, and what procedures are

followed by a computer control program called a production supervisor which guides the computer through several hours of computations.

The Designer's Apprentice helps turn a description of a weapon into a particular design by integrating numeric calculation with symbolic calculation. The goal is to allow the designer to describe the design in commonly-used design terms. It will aid in refinement of the design, recall related design problems, invoke standard simulation codes, and assist with parameter studies and interpretation of results. Code for the apprentice is still being written by Jack Aldridge, John Cerutti, Willard Draisin and Michael Steuerwalt, all of Los Alamos.

The researchers made a Portable Standard LISP version of Procon to run on the Cray, but never ran it because it could not be fully implemented. Now they are using Franz LISP with MIT macro enhancements.

The researchers also found that their system will run on a VAX 780, but Los Alamos scientists prefer to work on the Cray and do not want to learn the VAX operating system.

6.5 Westinghouse

Artificial Intelligence Designs Aircraft Avionics

Westinghouse is using an expert system to configure electrical system components for aircraft, based on the needs of the individual aircraft, to improve cost estimates and system performance.

The system, built with the expert system building tool OPS5 on a DEC VAX 11/750, was described in a paper by Westinghouse officials Ting-Long Ho, Robert A. Bayles and Edward R. Sieger at the National Aeronautics and Electronics Conference (NAECON) in Dayton.

The system picks modules required by Variable Speed Constant Frequency electrical generating systems that are now being used in new military aircraft and will soon be used on commercial aircraft. In the past, each order had to be designed separately, while constant-speed drive systems offered by competitors needed little or no redesign.

Some examples of options which a customer might want are: a speed increaser on the generator to match engine speed to generator speed requirements, "paralleling in" the generator control unit to provide coordination between multiple generators on the aircraft, and optional 28V DC power from the system.

The expert system queries the user for specification parameters, uses them to choose the correct modules, includes parts numbers and component sizing, and stores the results. Modules can include (using the generator as an example): stators, rotors, shafts, oil pumps, bearings and rotating rectifiers.

Some of the values a customer can specify include:

---minimum/maximum engine speed,

---electrical ratings,

---harmonic distortion percentages,

---MIL-STD-1553B required,

---load specifications in amps of 28V DC power supply.

If the system fails to meet a goal specified by the customer, the expert system can explain why. For example, there may not have been room in the aircraft for the components required.

The system has met its goal of relieving engineers from many of the details necessary to quote and design an electrical system. It does not replace the engineer, but provides a basic tool to develop basic designs which will be consistent from job to job. The engineer gains more time to do engineering, and the salesman quotes more accurate prices.

Future modifications to the system include an improved user interface and calculation modules which will be developed in FORTRAN, since OPS5 will only do 16-bit integer arithmetic.

The system helps overcome slow feedback between the customer and engineer. Feedback was complicated in the past because an engineer tends to know only his area of expertise.

OPS5 won high praise from the researchers. It was chosen because it is available commercially and has been used successfully in a number of related expert system. It was also easy to learn and use, and had the power to create large, complex system.